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PERFORMANCE ANALYSIS OF MULTI LEVEL BASED ON SINUSOIDAL PWM AND SPACE VECTOR PWM

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Abstract
This research focuses on the suitability of multi-level inverters for controlling induction motors, particularly in high voltage and power applications. Multi-level inverters offer advantages such as reduced voltage stress on switching devices and decreased harmonic distortion in the output.
The study evaluates the performance of two-level and three-level voltage source inverters using sinusoidal pulse width modulation (SPWM) and space vector pulse width modulation (SVPWM). The induction motor serves as the load to demonstrate the effectiveness of the proposed inverter system. The project analyzes the harmonic content in the inverter output voltage and studies the speed of the induction motor under various loads in the MATLAB/Simulink environment.
The simulation results highlight the effectiveness of the suggested inverter system by significantly reducing overall harmonic distortions in the output voltage through the application of different pulse width modulation techniques. Additionally, the study showcases the inverter's ability to regulate the speed of the induction motor at different loads effectively.
Overall, this investigation demonstrates the potential of multi-level inverters as a reliable solution for controlling induction motors in high-power applications, offering improved voltage waveforms and enhanced motor performance by minimizing harmonic distortions.
Keywords: Two-level inverter, Three-level inverter, Sinusoidal pulse width modulation (SPWM), Space vector pulse width modulation (SVPWM), Load demonstration.

I. INTRODUCTION

In recent years, there has been a growing demand for high-power applications in various industries, including renewable energy systems, electric vehicles, industrial motor drives, and grid interconnections. The efficient and precise control of induction motors, which are widely used in these applications, is of paramount importance. Multi-level inverters have emerged as a promising solution to address the challenges associated with high voltage and power control, offering several advantages over conventional two-level inverters.
Multi-level inverters are power electronic devices that synthesize a high-quality output voltage waveform using a series of power semiconductor switches and capacitors. By utilizing multiple voltage levels, these inverters can significantly reduce voltage stress on the switching devices, leading to improved reliability and longer lifespan. Furthermore, multi-level inverters can effectively mitigate harmonic distortion in the output voltage, which is crucial for ensuring smooth motor operation and avoiding detrimental effects on the power grid and other connected equipment.
This research project aims to evaluate the suitability of multi-level inverters for controlling induction motors in high voltage and power applications. The focus lies on comparing and analyzing the performance of two different types of multi-level voltage source inverters: the two-level and three-level inverters. Both inverters are implemented with two widely used modulation techniques: sinusoidal pulse width modulation (SPWM) and space vector pulse width modulation (SVPWM).
The primary objective of the study is to assess the effectiveness of the proposed inverter system in terms of harmonic distortion reduction and speed regulation of the induction motor. The inverter system is evaluated under varying loads to demonstrate its adaptability and robustness in different operating conditions.

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II. METHODOLOGY

MULTI LEVEL INVERTER

A Multi-Level Inverter (MLI) is a power electronic device that converts direct current (DC) to alternating current (AC) with multiple levels of voltage output. Unlike traditional two-level inverters, which provide binary voltage levels (typically +Vdc and -Vdc), Multi-Level Inverters can produce several discrete voltage levels. These additional voltage levels result in a more sinusoidal output waveform, reduced harmonic content, and lower electromagnetic interference (EMI).

The main advantage of Multi-Level Inverters is their ability to achieve higher voltage levels without the need for extremely high switching frequencies. This characteristic makes them suitable for various applications, including renewable energy systems, electric vehicle drives, motor drives, and high-power applications.

There are different topologies of Multi-Level Inverters, some of which include:

- **Diode-Clamped Multi-Level Inverter (Neutral-Point Clamped Inverter):** This topology uses diodes and capacitors to create multiple voltage levels between the DC link and the neutral point. It offers medium voltage capabilities but may require a large number of components.
- **Flying Capacitor Multi-Level Inverter:** Flying capacitors are used to create the additional voltage levels, allowing the inverter to reach medium to high voltage levels.
- **Cascaded H-Bridge Multi-Level Inverter:** In this topology, several H-bridge cells are connected in series to achieve the desired voltage levels. Each H-bridge generates a portion of the output voltage.
- **T-Type Multi-Level Inverter:** This topology uses two separate DC sources and switches to generate multiple voltage levels. It can reach high voltage levels with relatively simple circuitry.
- **H6 Multi-Level Inverter:** This is an extension of the T-Type inverter, using six separate DC sources to achieve even more voltage levels.

The control techniques for Multi-Level Inverters can vary, and the choice of control strategy impacts the inverter's performance, efficiency, and harmonic content. Popular control techniques include Sinusoidal Pulse Width Modulation (SPWM) and Space Vector Pulse Width Modulation (SVPWM), which regulate the inverter's output voltage by adjusting the switching pattern of the power devices.

Multi-Level Inverters have gained popularity in various applications due to their ability to achieve high voltage and low harmonic distortion, resulting in improved energy efficiency and reduced stress on connected devices. However, they come with challenges such as complex control algorithms, increased component count, and potential switching losses. Nonetheless, advances in power electronics technology continue to enhance the efficiency and practicality of Multi-Level Inverters for a wide range of applications.

SPWM ANDSVPWM TECHNIQUE

SPWM (Sinusoidal Pulse Width Modulation) and SVPWM (Space Vector Pulse Width Modulation) are two widely used control techniques in power electronics, particularly in voltage source inverters and multi-level inverters. Both techniques are employed to generate AC output voltages with desired characteristics, such as sinusoidal waveforms, low harmonic distortion, and efficient utilization of DC voltage sources.

- **SPWM (Sinusoidal Pulse Width Modulation):** Sinusoidal Pulse Width Modulation is a control technique that generates a series of pulses with varying widths to synthesize an output voltage waveform that closely resembles a sinusoidal waveform. The technique involves comparing a sinusoidal reference signal (usually the desired output voltage) with a high-frequency triangular carrier waveform. The result of the comparison determines the pulse width of the output pulses. If the reference signal is higher than the carrier waveform, a positive pulse is generated; otherwise, a negative pulse is generated.

The duty cycle of the pulses is adjusted in real-time to regulate the output voltage amplitude and frequency. By controlling the pulse width based on the reference signal, SPWM achieves voltage control and can effectively reduce harmonic distortion in the output voltage waveform. However, SPWM may produce more harmonic content compared to SVPWM.

- **SVPWM (Space Vector Pulse Width Modulation):** Space Vector Pulse Width Modulation is a more advanced control technique that provides a higher level of output voltage control and lower harmonic distortion compared to SPWM. Instead of using a triangular carrier waveform, SVPWM

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operates in a two-dimensional space called the "alpha-beta" plane. It decomposes the reference signal into two orthogonal components, namely the α-axis and β-axis components. The components are then combined to create a voltage vector representing the desired output voltage.

The voltage vector is positioned in the α-beta plane, and the inverter is controlled to produce the necessary voltage and phase angle to track this vector. The switching sequence is determined based on the angle of the voltage vector, ensuring that the output voltage waveform follows the desired trajectory. SVPWM allows for more precise control of the output voltage and, by properly selecting the switching states, can eliminate some lower-order harmonics entirely, leading to lower total harmonic distortion in the output waveform.

Compared to SPWM, SVPWM offers higher efficiency, improved voltage utilization, and reduced voltage ripple. However, SVPWM requires more complex control algorithms and computational resources due to its vector-based approach.

Both SPWM and SVPWM are commonly used in various applications, including motor drives, grid-tied inverters, renewable energy systems, and industrial power electronics. The choice between SPWM and SVPWM depends on the specific application requirements, system complexity, and desired output waveform quality.

RENEWABLE ENERGY

Renewable energy refers to energy sources that are naturally replenished and have a minimal impact on the environment compared to fossil fuels and other non-renewable energy sources. These sources harness energy from natural processes or phenomena, such as sunlight, wind, rain, tides, geothermal heat, and biomass, and convert it into usable forms of energy for various applications.

The key characteristics of renewable energy are sustainability, low or zero carbon emissions, and the ability to generate energy indefinitely without depletion. As the world faces challenges related to climate change, air pollution, and the finite nature of fossil fuels, renewable energy has emerged as a crucial solution to address these issues and transition towards a more sustainable energy future.

Some of the most common types of renewable energy sources include:

- ✓ **Solar Energy:** Capturing sunlight using photovoltaic (PV) cells or solar thermal collectors to produce electricity or heat water for domestic and industrial use.
- ✓ **Wind Energy:** Harnessing the kinetic energy of wind through wind turbines to generate electricity.
- ✓ **Hydropower:** Converting the potential and kinetic energy of flowing or falling water into electricity using hydroelectric power plants.
- ✓ **Geothermal Energy:** Tapping into the Earth's heat to produce electricity or provide heating and cooling through geothermal power plants or geothermal heat pumps.
- ✓ **Biomass Energy:** Utilizing organic materials, such as agricultural residues, wood, and organic waste, to produce biofuels or generate heat and electricity through biomass power plants.
- ✓ **Ocean Energy:** Extracting energy from the tides and waves (tidal energy and wave energy) or the temperature difference between deep and shallow waters (ocean thermal energy conversion).

Renewable energy sources offer several advantages:

- ➢ **Environmental Benefits:** They produce little to no greenhouse gas emissions, reducing the contribution to climate change and air pollution.
- ➢ **Sustainability:** Being naturally replenished, they provide a long-term and stable energy supply.
- ➢ **Energy Independence:** By diversifying the energy mix, countries can reduce their dependence on fossil fuel imports and enhance energy security.
- ➢ **Job Creation:** The renewable energy sector creates jobs in manufacturing, installation, maintenance, and research and development.
- ➢ **Reduced Costs:** As technology advances and economies of scale improve, the cost of renewable energy has been decreasing, making it increasingly competitive with conventional energy sources.

However, renewable energy also faces challenges, such as intermittency (in the case of solar and wind energy), land and resource use concerns, and the need for energy storage and grid integration solutions to ensure reliable power supply.

The global shift towards renewable energy is essential for achieving sustainable development goals, mitigating climate change, and ensuring a cleaner and more resilient energy future. Governments, businesses, and individuals are increasingly embracing renewable energy solutions to accelerate the transition away from fossil fuels and promote a greener and more sustainable planet.

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III. RESULTS & DISCUSSION

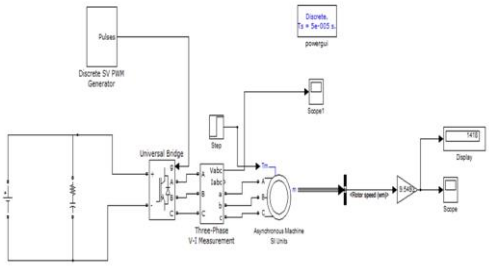

Figure 1: 2-level inverter based on sinusoidal PWM technique.

Table 1:2-level SPWM speed at different loads

2-level SPWM speed at different loads		
s.no	**load**	**speed (RPM)**
1	Quarter load	1413
2	Half load	1409
3	Three quarter loads	1406
4	Full load	1402

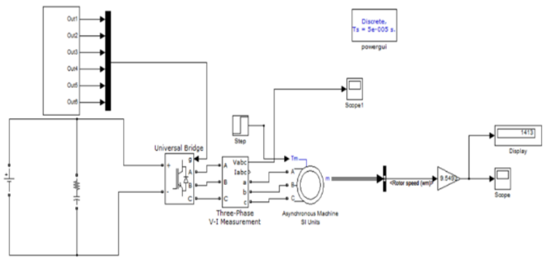

Figure 2: 2-level inverter based on space vector PWM technique.

Table 4.2: 2-level SVPWM speed at differentloads

2-level SVPWM speed at different loads		
s.no	**load**	**Speed (RPM)**
1	**Quarter load**	**1418**
2	**Half load**	**1416**
3	**Three quarter loads**	**1414**
4	**Full load**	**1412**

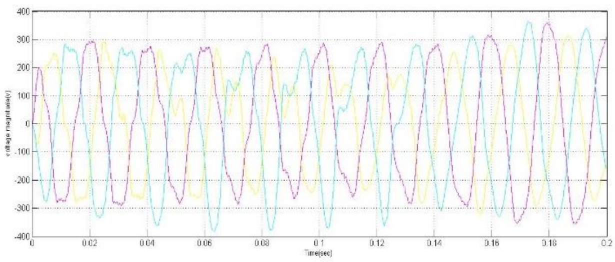

Figure 3: Output voltage waveform of 2 level inverter based on sinusoidal PWM.

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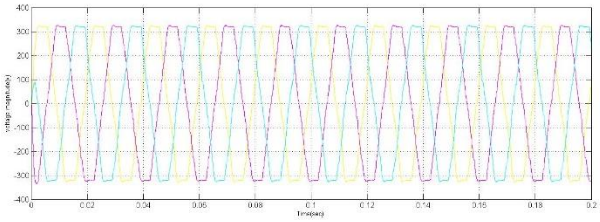

Figure 4: Output voltage waveform of 2 level inverter based on space vector PWM.

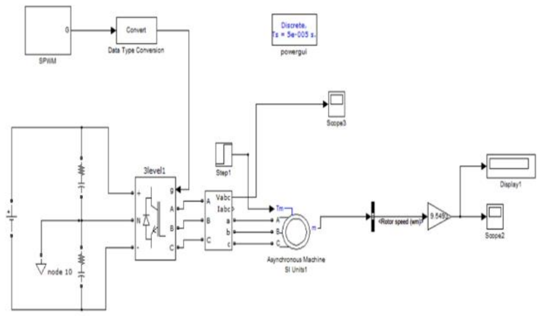

Figure 4: 3-level inverter based on sinusoidal PWM technique.

Table 3: 3-level SPWM speed at different loads

3-level SPWM speed at different loads		
s.no	load	speed (RPM)
1	Quarter load	1423
2	Half load	1420
3	Three quarter loads	1417
4	Full load	1415

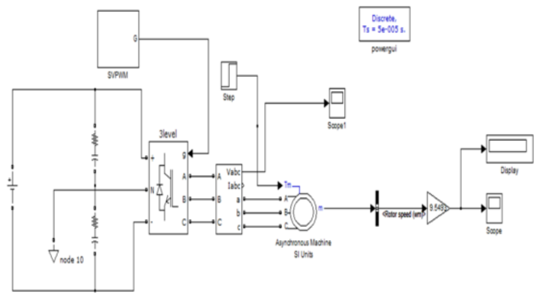

Figure 4: 3-level inverter based on space vector PWM technique.

Table 4: 3-level SVPWM speed at different loads

3-level SVPWM speed at different loads		
s.no	load	speed (RPM)
1	Quarter load	1428
2	Half load	1424
3	Three quarter loads	1422
4	Full load	1420

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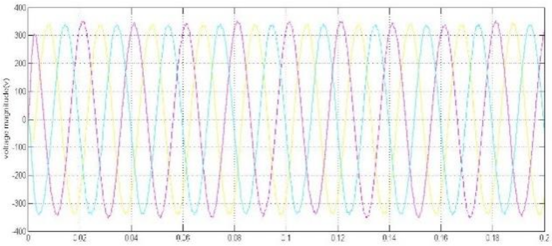

Figure 6: Output voltage waveform of 3 level inverter based on sinusoidal PWM.

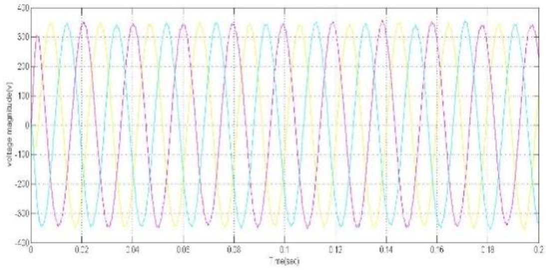

Figure 7: Output voltage waveform of 3 level inverter based on space vector PWM.

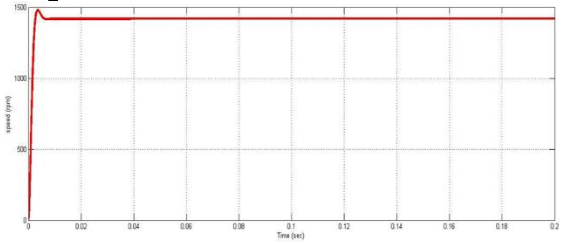

Figure 8: Output speed waveform of 2-level inverter based on Sinusoidal PWM.

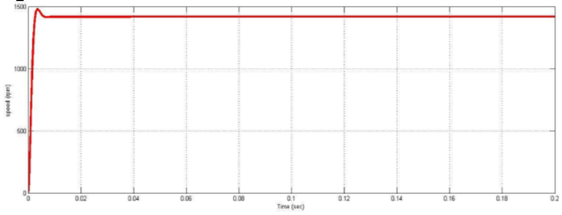

Figure9: Output speed waveform of 2-level inverter based on Space vector PWM.

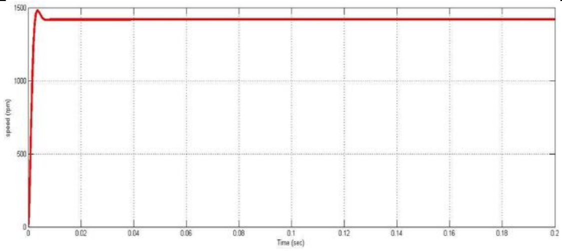

Figure 10: Output speed waveform of 3-level inverter based on Sinusoidal PWM.

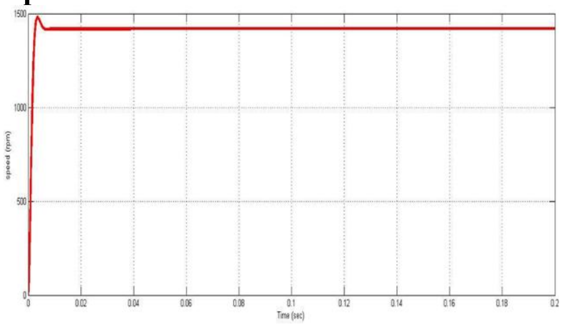

Figure 11: Output speed waveform of 3-level inverter based on Space vector PWM.

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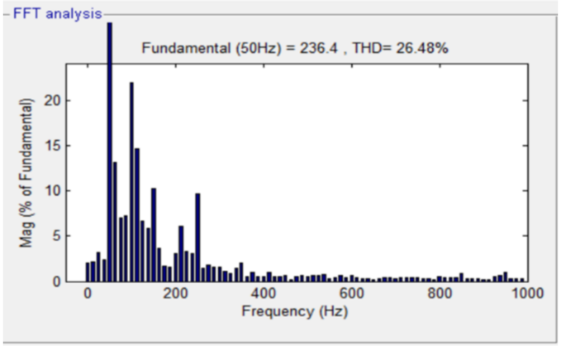

Figure 12: THD waveform of 2level inverter based on sinusoidal PWM using FFT analysis.

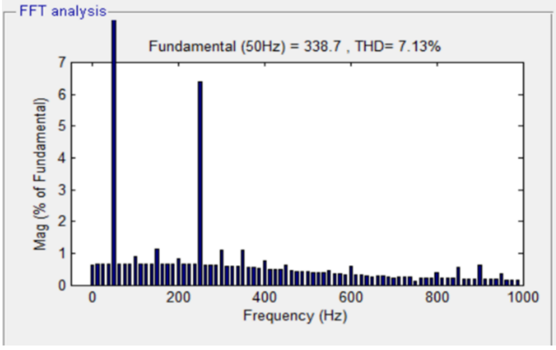

Figure 13: THD waveform of 2level inverter based on Space vector PWM using FFT analysis.

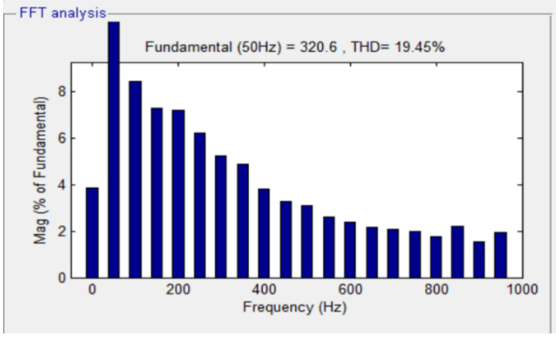

Figure 14: THD waveform of 3level inverter based on sinusoidal PWM using FFT analysis.

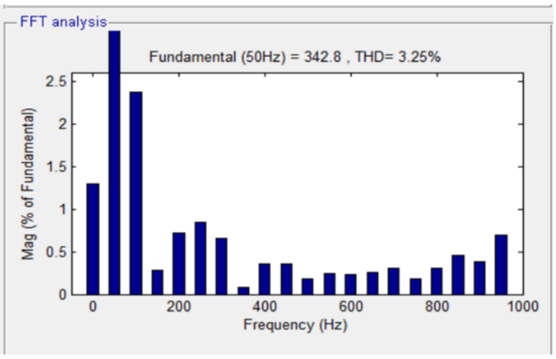

Figure 15: THD waveform of 3level inverter based on Space vector PWM using FFT analysis.

Table 4.5: THD of 2-level and 3-level based on sinusoidal PWM and space vector PWM.

No of level	SPWM	SVPWM
2 level	26.86%	7.13%
3 level	19.45%	3.25%

IV. CONCLUSION

In conclusion, this research project focuses on evaluating the suitability of multi-level inverters for controlling induction motors, particularly in high voltage and power applications. Multi-level inverters have been investigated as promising solutions due to their ability to address key challenges,

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such as reduced voltage stress on switching devices and decreased harmonic distortion in the output voltage. These advantages make them highly relevant in industries like renewable energy systems, electric vehicles, industrial motor drives, and grid interconnections.

The study specifically evaluates the performance of two types of multi-level voltage source inverters: the two-level and three-level inverters, utilizing two widely used modulation techniques - sinusoidal pulse width modulation (SPWM) and space vector pulse width modulation (SVPWM). The induction motor is employed as the load to demonstrate the effectiveness of the proposed inverter system in controlling motor speed and minimizing harmonic distortions.

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