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SMART CONTROL OF VOLTAGE SOURCE INVERTERS USING PWM TECHNIQUES

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ABSTRACT: This project involves using advanced pulse width modulation (PWM) techniques to intelligently manage voltage source inverters (VSIs) to improve power electronic system efficiency and functionality. Voltage source inverters transform DC electricity into AC power for motor drives, renewable energy systems, and UPSs. The paper uses intelligent control strategies and pulse width modulation (PWM) techniques such adaptive modulation, space vector PWM, and sinusoidal PWM to reduce harmonic distortion, output voltage regulation, and switching losses. This paper examined how digital controllers and real-time control algorithms can keep inverters running smoothly under changing load and supply conditions. These methods improved energy conversion system efficiency and stability.

Keywords: *Voltage Source Inverter (VSI), Pulse Width Modulation (PWM), Sinusoidal PWM, Space Vector PWM, Harmonic Reduction,*

I. INTRODUCTION

Voltage Source Inverters (VSIs) convert DC to AC. Electric vehicles, power sources, and renewable energy systems use them. The stability and quality of a voltage source interface (VSI) output voltage depend on its control, regardless of input or load conditions. Smart control solutions are needed more than ever as renewable energy sources and sensitive technology burdens increase.

Due to its output waveform manipulation, pulse width modulation (PWM) is commonly employed to control voltage source inverters (VSIs). By modifying switching pulse duration using pulse width modulation, the inverter may produce a nearly linear output with low harmonic distortion. Old approaches like sinusoidal PWM and space vector PWM may lose accuracy and efficiency when facing dynamic changes or fluctuating loads.

To overcome these issues, smart control approaches and PWM schemes have been created. These technologies optimise inverter performance using complex methods including adaptive control, fuzzy logic, and neural networks. Intelligent controllers improve the inverter's ability to respond to disturbances, maintain stable voltage, and increase efficiency by continually monitoring system parameters and changing switching operations.

Integrating intelligent control and PWM approaches improves VSI functionality and reliability. The system becomes better at handling uncertainty, responding faster, and reducing total harmonic distortion. Modern digital processors and embedded systems provide real-world intelligent control approaches. This makes power electronics research on them crucial.

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II. LITERATURE SURVEY

Sharma, R. (2025) :R states that intelligent control methods in voltage source inverters need better pulse width modulation (PWM). Sharma 2025. PWM and machine learning improve real-time switching decisions and harmonic distortion, according to the paper. Industries used complex control methods to improve power efficiency and quality. Sharma says flexible PWM management decreases switching losses and improves inverter reliability in response to load changes.

Kumar, S. (2024) :Kumar, S. Kumar (2024) studied fuzzy logic controllers that used PWM to govern clever inverters. Fuzzy-based PWM control improved voltage stability and THD in the paper. Kumar believes this is possible because sophisticated inverters can handle nonlinear loads and variable input circumstances. The research found that more advanced PWM approaches produce a more stable, energy-efficient system.

Lee, J. (2023):Lee, J. Lee examined the effectiveness of neural network-based control approaches using pulse width modulated voltage source inverters in 2023. Using neural networks, anticipatory switching control can increase inverter system sensitivity to changes. The models used real-time data to optimize output waveforms and eliminate system errors. Lee said smart control and PWM gave renewable energy customers more alternatives.

Patel, M. (2022) :Patel used digital control and SVPWM to increase inverter performance in 2022. The paper found that digital controllers had better timing and modulation. Patel claims that intelligent control solutions reduced power fluctuations and increased system resilience. The results show that advanced power electronics applications require sophisticated PWM algorithms.

Nguyen, T. (2021) :In 2021, Nguyen and T. Nguyen studied pulse width modulation-based voltage source inverter adaptive control approaches. The findings show that adaptive PWM systems can independently respond to various load circumstances to sustain output voltage. Intelligent control made the system less unpredictable and inverters more efficient, according to Nguyen. The paper found that PWM and adaptive algorithms improve inverter performance.

Garcia, L. (2020) :Garcia, L. discussed voltage source converters. (2020) explored traditional and novel PWM regulation approaches. The paper found that intelligent PWM approaches used less energy and had fewer harmonics. Garcia said smart controls and PWM helped identify flaws and monitor the system. The paper showed that inverter technology development is increasingly dependent on complex control systems.

III. VOLTAGE SOURCE INVERTERS

Waveform generators help static power converters convert DC to AC. Voltage compensators, active filters, static variable compensators, UPS, and ASDs use these patterns for various functions. Controlling sinusoidal AC output intensity, frequency, and phase is essential.

Because each topology's AC output is managed independently and resembles a voltage waveform, they're called voltage source inverters. Adjustable speed drives (ASDs) are inverters' main industrial use. These designs are most common since they can generate voltage. These topologies have a controlled AC output that resembles a current waveform. They're called current source inverters because of this. Industrial applications that require

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high-quality medium-voltage power patterns use these structures. Inverters and static power converters use power switches to generate discrete alternating current output patterns. WAVs have harsh variations instead of smooth ones.

A typical ASD's VSI produces a three-level alternating current output voltage (Fig. 1c). Despite not working as expected, the fundamental waveform component is sinusoidal (Fig. 1b). If you want the power switches to work this way, modulate them. Space-vector (SV), selective-harmonic-elimination (SHE), and carrier-based approaches like SPWM are the most used modulation methods.

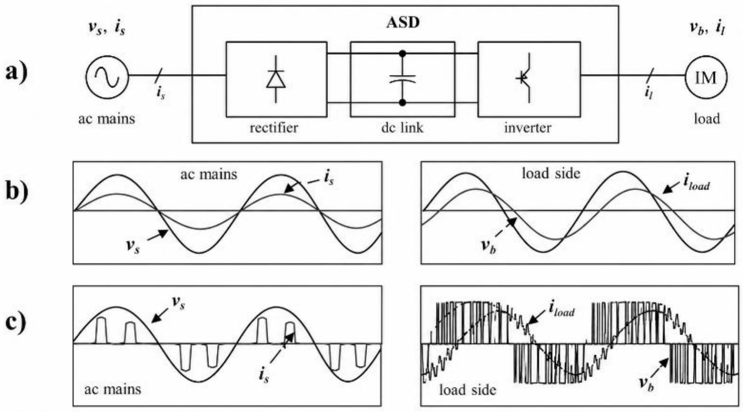

Figure 1: shows a standard variable speed drive voltage source inverter. Alternating current is produced.

a) The electrical power conversion topology;
b) The ideal input (ac mains) and output (load) waveforms; and
c) The actual input (ac mains) and output (load) waveforms.

Single-Phase Voltage Source Inverters

Single-phase voltage source inverters (VSIs) can be half-bridge or full-bridge. Single-phase UPS systems and power supplies use them despite their reduced power storage capacity. They are also being used in multicell high-power static power systems.

Half-Bridge VSI

Figured inverter uses half-bridge voltage source. Two. Two huge capacitors, one of which maintains (Vi)/2, are needed to establish a neutral point N. The inverter generates low-order current harmonics, requiring two large capacitors (C+ and C-). We cannot engage switches S+ and S- simultaneously because a short circuit across the DC link voltage source Vi is possible. The switch has three states: 1, 2, and 3. The table shows this. Only state 3 is unknown.

To prevent DC bus short circuits and maintain a consistent AC output voltage, the modulation strategy must always engage the inverter leg upper or lower switch.

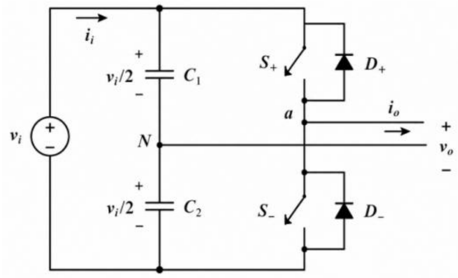

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Fig. 2: Single-phase half-bridge VSI.

Full-Bridge VSI

Create picture. Figure 3 shows a full-bridge voltage source inverter (VSI). It looks like a half-bridge inverter, but it has a load neutral limb. As planned, activating switches S1+ and S1- (or S2+ and S2-) simultaneously shorts the dc link voltage source Vi. Table 2 lists four switch states: 1, 2, 3, and 4, plus an unidentified fifth. Avoid the undefinable state to accurately measure AC output voltage. Use ac output voltage to calculate dc link value Vi. It's twice as high as half-bridge VSI topologies. Many approaches have been proposed for modulating full-bridge VSIs. These include unipolar or bipolar PWM.

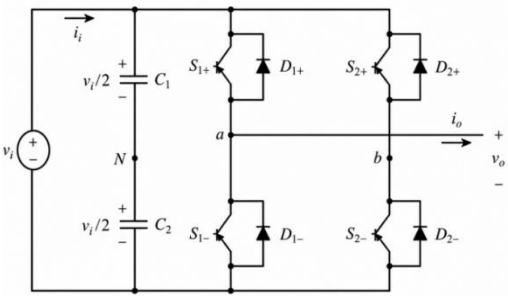

Fig. 3: Single-phase full-bridge VSI.

Three Phase Voltage Source Inverters

Three-phase voltage source inverters are used in medium-to-high-power applications. Low-power applications use single-phase VSIs. These designs aim to construct a three-phase voltage source with exact phase, amplitude, and frequency control. Newer applications like active filters and voltage compensators demand random voltages, however sinusoidal voltage patterns are usually required. Later uses include ASDs, UPSs, FACTS, and VAR compensators.

Create picture. shows a typical three-phase inverter arrangement. The switch has eight states, as shown in Table 3. S1 and S4, S3 and S6, or S5 and S2 controls cannot be activated concurrently, as with single-phase voltage source inverters. A brief DC connection voltage supply circuit would result. If both switches on the voltage source inverter (VSI) are disengaged, the VSI will enter an unsure condition and create AC output line voltages based on the line current direction. Two of the eight allowed nationalities (rows 7 and 8 of the table).

Table 3 covers the remaining states with non-zero alternating current output values from 1 to 6. Since AC line currents pass through the lower or upper parts, the voltages are zero at this point. The inverter switches phases to create a voltage pattern. The figure's design has three AC output line voltages: Vi, 0 and -Vi. Four, not one. Modulation selects states needed to generate the desired waveform. This ensures only certified states are used.

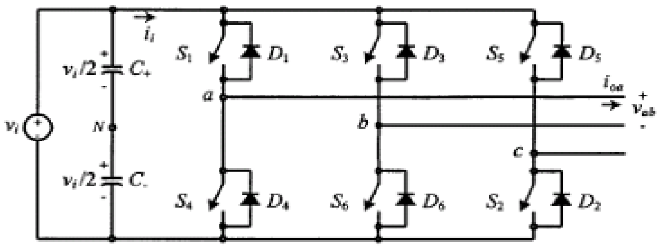

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Fig.4: Three-phase VSI topology.

IV. PULSE WIDTH MODULATION IN INVERTERS

Output voltage from an inverter can also be adjusted by exercising a control within the The integrated control of an inverter can change its power output. Use the inverter's pulse-width modulation setting for best results.

In reaction to a steady DC input voltage, the inverter adjusts component operation duration to maintain AC output voltage. Most voltage output modifications use pulse width modulation (PWM).

Additionally, PWM approaches have these benefits:

- This approach modifies output voltage without additional components.
- While controlling output voltage, this method can also minimize lower-order harmonics.
- Filtering is less needed since higher-order harmonics are easily eliminated. SCRs are expensive and need rapid activation and deactivation, which is their main drawback.

Industry uses PWM transformers widely. Plasma wave modulation (PWM) uses constant-amplitude pulses. Adjusting pulse breadth changes the inverter's output voltage and reduces harmonics.

PWM has many uses:

- One pulse variation
- Different pulse durations
- Sinusoidal and carrier-based PWM

V. MATLAB SIMULATIONS

Many open loop approaches use space vector pulse width modulation and the constant voltage to frequency principle to control induction motor speed.

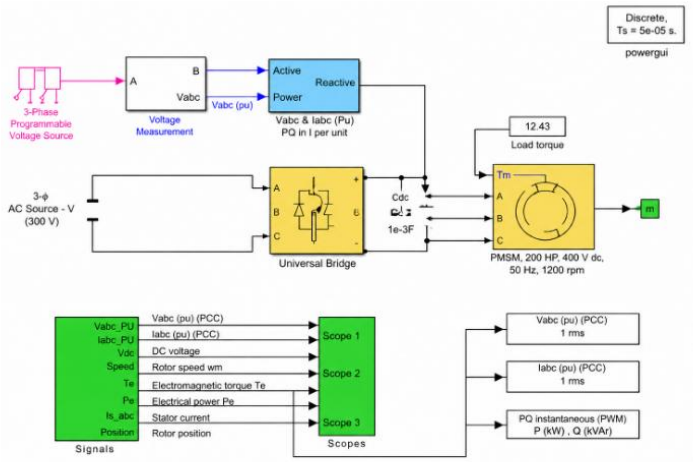

Fig5.1: Open loop speed control of an induction motor using a space vector PWM modulator

Circuit description:

A 325 V DC power supply supplies a 3-phase squirrel-cage motor with 3 HP, 220 V, 60 Hz, and 1725 rpm via a 3-phase MOSFET inverter. The "Asynchronous Machine" block represents the motor, while the "Universal Bridge" block represents the inverter. Increase the stator leakage inductance Lls by two to filter the real inverter.

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This design places the reactor between the generator and machine. The shaft of the machine can handle a continuous load torque of 11.9 N·m. Inverter discharge pulses are generated via the SPS library "Space-Vector PWM modulator" function. When the incoming reference vector is "Magnitude-Angle," the slicing frequency is 1980 Hz.

The "Constant V/Hz" block controls motor speed. Speed set points control motor-stator electricity frequency and quantity. Stator flux is maintained by controlling voltage and frequency.

Demonstration:

We started modeling. Since the starting state data will be provided automatically, the exercise should start stable. The stator voltage must be 220V @ 60Hz to run the motor at 1720 RPM. The change from 1725 to 1300 RPM takes 0.1 second. Scope 1 shows the methodology. The RMS stator voltage drops to 165.8V and the frequency to 45.2 Hz when the motor stabilizes at 1275 RPM. The "V-I Stator" Scope shows the stator's phase A current and phase AB voltage contours. Power GUI FFT Analysis can FFT these two values.

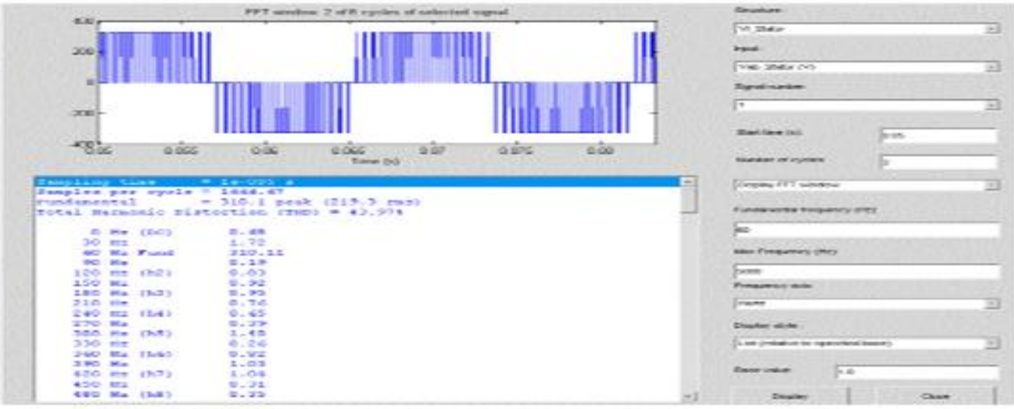

Fig5.2: FFT of stator phase voltage and current waveforms.

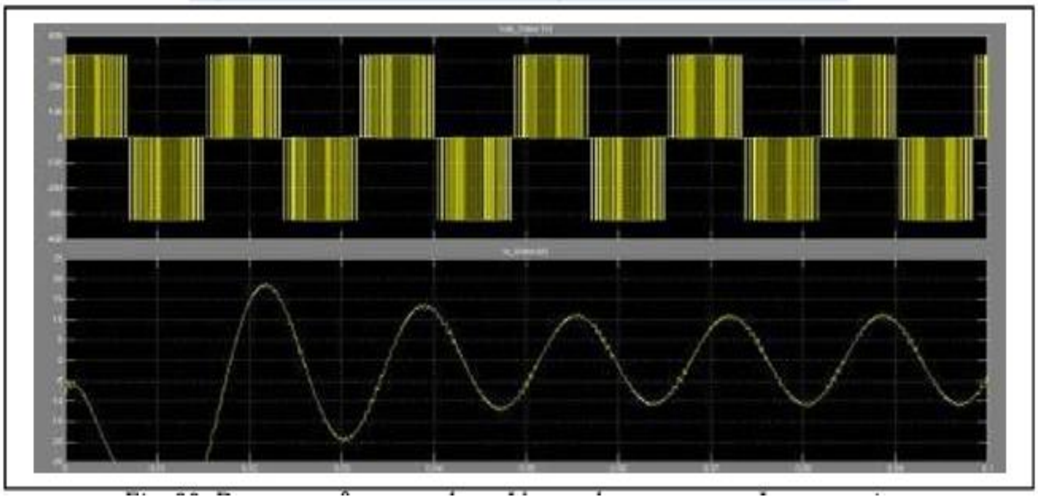

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Fig5.3: Response of stator voltage Vab and stator current Ia versus time

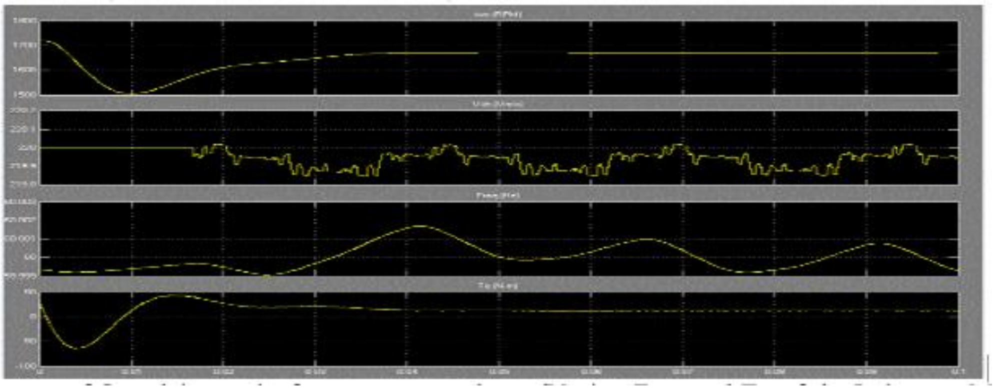

Fig5.4. Response of Speed (in rpm) of rotor, stator voltage (Vab), Freq and Te of the Induction Motor versus time

Model for three-phase two level PWM voltage source motors

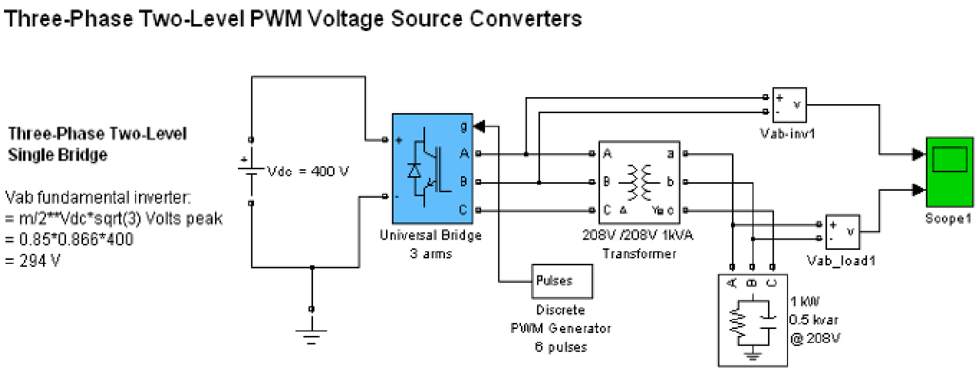

Fig5.5 Model for three-phase two level PWM voltage source motors

Circuit description:

A separate system circuit shows a three-phase, two-level PWM voltage source inverter. A three-phase transformer supplies the inverter with one kilowatt, five-phase, sixty-hertz, 208-volt rms AC. The Extras/Discrete Control Blocks module's Discrete PWM Generator regulates an open loop. This circuit uses f = 60 Hz, m = 0.85, Vdc = 400 V, and 1080 Hz carrier. This transformer's 8% leaky inductance and 500 var load capacitance make it suitable for harmonic filtering.

Simulation:

The first trace indicated the voltage of the PWM inverter, and the second trace displayed the voltage of the load. I saw these two patterns in the Scope block as soon as I opened the simulation. After the exercise, open Powerful's "FFT Analysis" option. After that, the signal's frequency range is clear. From 0 to 5000 Hz.

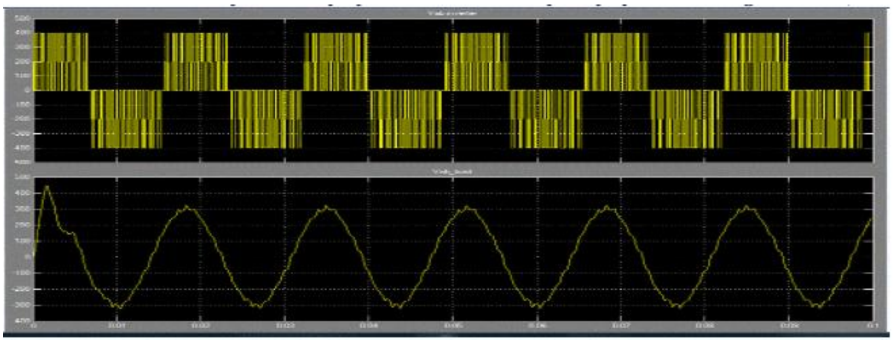

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Fig5.6 Response of Vab Load and Vab Inverter versus time

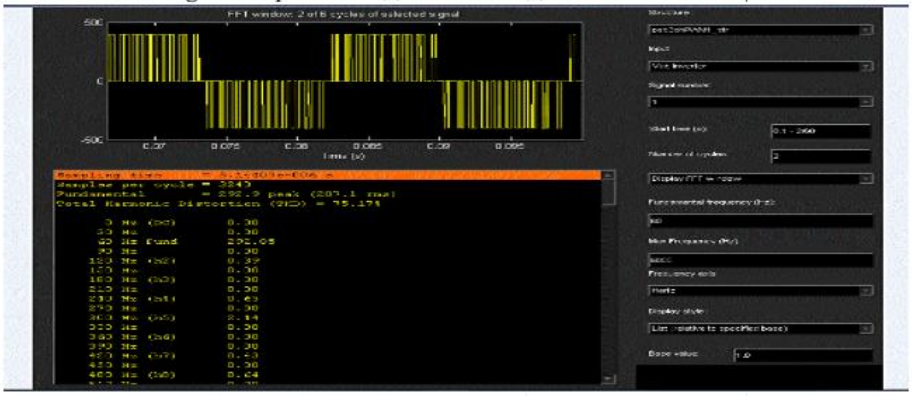

Fig.5.7 'FFT Analysis' to display the 0-5000 Hz frequency spectrum of signal saved

VI. CONCLUSION

Finally, intelligent regulation of voltage source inverters using pulse width modulation (PWM) is a revolutionary way to improve power electrical system efficiency. Intelligent control approaches mixed with standard PWM methods improve voltage regulation, load adaptation, and harmonic distortion. These changes improve energy efficiency and dependability in many situations, such as green power integration and factory electric motor use. As science and technology evolve, PWM-based control systems should enable more efficient, intelligent, and reliable power conversion solutions.

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