Multilevel Inverter with Enhanced THD Value used in Grid Connected Applications

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Abstract: - In this work, the relationships among pulse width modulation (PWM), sinusoidal pulse width modulation (SPWM), and space-vector pulse width modulation (SVPWM) for three-phase inverters will be analyzed to better comprehend their differences. detailed comparison of the three modulation schemes under study's Total Harmonic Distortion (THD). High-power applications are increasingly concentrating on converter technology. This growing importance may be attributed to its improved output waveforms over the $3\text{-}\varphi$ carrier-based sinusoidal pulse width modulation (SPWM). To control and modulate multi-level inverters, many techniques are employed. These methods are categorized based on how frequently they switch. The ripple current rating, capacitance value, and voltage balance in the DC bus capacitors are all impacted by the pulse width modulation techniques. It is crucial to select the modulation method based on the current control requirements, as this determines the output voltage waveform's harmonic content. SVPWM is gradually becoming more and more popular in industries because of its improved dc bus utilization and ease of digital realization. This work examines PWM, Sinusoidal, and SVPWM feeding a load connected to RL. Three different methodologies' performances are compared as these methods are investigated through simulation with MATLAB/SIMULINK software.

Key-Words: - Power grid, PWM Techniques, SVPWM, Voltage Source Inverters, Total Harmonic Distortion (THD), Three-phase inverter, Switching devices, Variable frequency drives.

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1 Introduction

A certain amount of the power generated by the non-renewable plant is inserted by the distributed generating systems at specific transmission locations, rather than being used by the loads entirely. Because all transmission systems operate on AC, these sources need voltage source inverters (VSIs) to introduce active and reactive energy into the system by converting DC to AC. Thus, a fraction of the power demand is satisfied via dispersed generation. Power electronic devices like MOSFETS and IGBTS are included in VSI. The harmonics issue in the system could be brought on by often switching these devices to convert DC to AC power. The SVPWM control-based scheme is utilized for the inverter, to obtain the reduced harmonic content output voltage at the distributed generating systems end. Here, SVPWM for power converters is recommended to assist lower the system's harmonics. The input side modulating signals in this case are added up to a predetermined voltage, [1], [2]. Afterward, they undergo differentiation using carriers to generate gating pulses for the inverter.

A higher Inverting voltage level indicates lower harmonic production which indicates that the multilevel inters play a vital, especially in high power applications which will reduce the overall voltage stress at the load side. The two broad categories into which the inverters fall are two-level and multilevel inverters. Reduced harmonic distortion is one benefit of multilevel inverters over two-level inverters, [3], [4]. The trapezoidal and sinusoidal current waveforms are obtained using a multilevel inverter which is exclusively useful in electric drive applications, a static VAR compensator, and an active power filter. AC Drives with higher performance always require accurate switching-based configuration of rectifiers and voltage-source inverters, [5]. On the other hand, the higher power losses are present in proportion to the increased switching frequency value. As a result, it may become less efficient and perhaps cause damage. Finding the best compatible modulation technique requires comparing the converter efficiency under various PWM schemes, [6]. Modulation signals and voltage space vectors were compared, and examples of both SPWM and SVPWM implementations are presented along with related solutions. Three-phase voltage source inverter (VSI) systems are examples of high-power applications that typically need lower levels of harmonic distortion and great efficiency. It is essential to regulate the voltage source inverters' output, [7]. Inverter gain can be controlled using a variety of methods, and the following Figure 1 illustrates the many modulation schemes for multi-level inverter topologies, [8].

The particular application requirements, such as the expected result waveform, efficiency, and control characteristics, determine which PWM approach is best. Different domains, including power electronics, motor control, communication systems, and audio processing, employ distinct methodologies. The technique known as pulse width modulation, or PWM, is effective in obtaining the necessary voltage or current to operate the load. Because the PWM approach can drive a load with a maximum output voltage and a lower harmonic current, it is becoming more and more popular for AC drives. PWM techniques are used in producing signals with quality amplitude and frequency which will help to reduce in THD value of the converters, [9], [10].

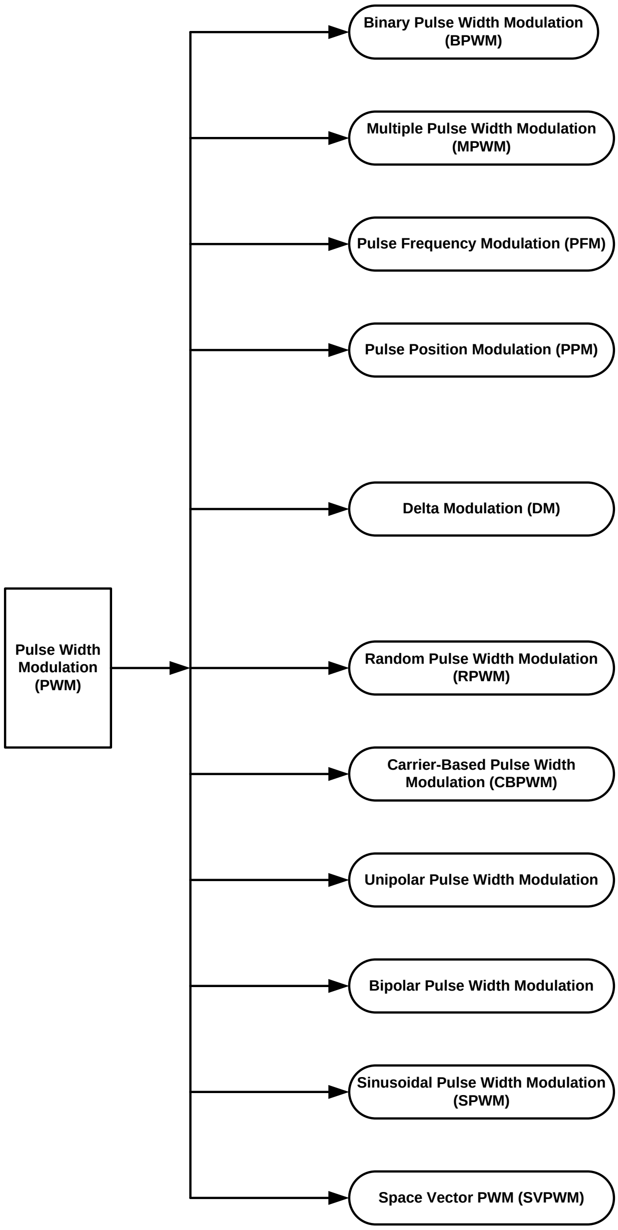

Fig. 1: Representation of various modulation techniques

2 About the SVPWM Technique

In the area of variable frequency drives (VFDs), the SVPWM technique is used in control systems and power electronics for electric motor applications. The switching devices like MOSFETs or IGBTs gating signals are controlled in the way of low harmonic production using advanced controlling techniques like SVPWM. The three-phase system instant current and voltage values are represented as a space vector in the SVPWM technique. To produce the final desired output waveform, the corresponding space vector values of the technique also change. In the case of the three-phase systems and electric motor application the SVPWM technique is used regularly, [11], [12], to obtain the controlled output voltage as per the requirement.

From the representation point of view the SVPWM technique is made with six different sectors and further, those will replicate the two different voltage vectors. The three-phase voltage regulation is always one of the key advantages while using this technique. The fundamental voltage component will increase in proportion with the active vector which is represented in the hexagon structure of the SVPWM technique on the output voltage following the zero-voltage vector. The reference vector in the hexagon always represents the projected voltage value of the system. The challenge is to estimate this Obtaining the reference vector based on the available active voltage vectors, without changing the balance of the three-phase system is one of the major challenges, [13].

The SVPWM can provide the required voltage vector using the switching mechanism. To evaluate the approximate reference vector, the SVPWM can find the active vectors' duty cycle with this reduced harmonic content waveforms are obtained in coordinating with the controlled switching signal provided to the power switching devices. Reduction of harmonic content distortion in the waveform will lead to improvement in the overall system efficiency which can be achieved through the SVPWM technique, [14]. Power electronic-based equipment like VFDs and UPS are normally equipped with the SVPWM technique since this apparatus requires precise three-phase voltage control. Design wise the SVPWM technique seems more complex on the other hand which provides more accurate dynamic performance which leads to a reduction of the harmonics of the output waveform. In run time SVPWM technique-based circuit is made based on advanced digital signal processors (DSPs) and Microcontrollers, [15], [16].

The six power switches designated S1 through S6, are responsible for shaping the output. The switching variables a, a1, b, b1, c, and c1 control this process. The appropriate lower transistor is turned off, meaning that the corresponding a1, b1, and c 1 is 0, when an upper transistor is switched on, that is, when a, b, or c is 1. Consequently, the output voltage may be determined by utilizing the on and off states of the higher transistors S1, S3, and S5. The voltage space vectors used in the traditional space vector modulation approach are taken from the grid's three-phase voltages, [17], [18].

Using a rotating reference vector made up of six fundamental non-zero vectors arranged in the shape of a hexagon, the SVPWM procedure is carried out around the state diagram. The reference angle, which ranges from 0° to 360°, is compared to the angle formed by the d-q quantity. The idea is used to determine the angle at which the reference voltage vector frames the various reference voltage sectors. This allows the reference voltage to function in all sectors at all angles, so covering its full 360° range of operation, [19], [20].

3 Block Diagram Representation with Proposed Techniques

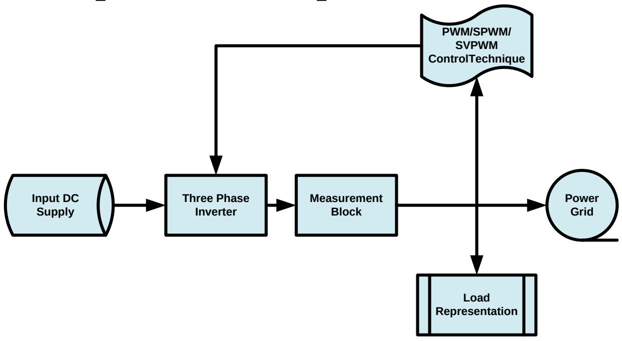

Fig. 2: Complete block diagram representation of with PWM/SPWM/SVPWM with grid-connected system

A block diagram of the full system with various modulation strategies to produce the better-performing one is shown in Figure 2. Here, the three-phase inverter's input DC voltage is taken from a non-conventional power-generating system, such as a solar power generation system. In addition, if the non-traditional power production system produces excess power, the three-phase inverter transforms the DC voltage into a three-phase AC supply for the utility and feeds the conventional grid system. A different mechanism is also developed to supply the supply frequency and the rectangular wave to the modulation block for the successful generation of the signals to the inverter. Controlled switching signals are generated in the modulation technique block by taking input current and voltage from the inverter output.

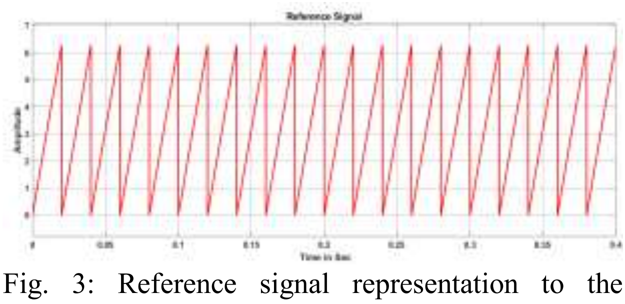

Fig. 3: Reference signal representation to the modulation technique

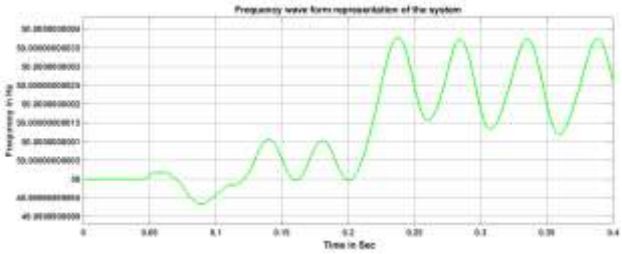

Fig. 4: Frequency waveform representation of the modulation techniques

Figure 3 and Figure 4 shows the reference sawtooth waveform and input frequency of the modulation techniques used in generating the controlled pulse signals to the three-phase inverter.

4 Simulation Results and Discussions

Simulations are mostly used in power electronic converter systems to analyze the design configuration and apply control strategies. The efficiency of the suggested methods is demonstrated by several MATLAB/Simulink simulation results for multilevel inverters with RL loads. Table 1 displays the line voltages and inverter output phase for the PWM, SPWM, and SVPWM techniques, along with a comparison of the related THD. For different switching frequencies, the total harmonic distortion and output load current was calculated using the load parameters R=10 ohms, L=6.5 mh, and an input DC source voltage of 300 v.The SVPWM-controlled fundamental line current and output phase current output waveforms are approximately equal to 25% more than SPWM output currents and 60% more than PWM output currents due to higher DC bus utilization in the SVPWM technique and lower THD compared to SPWM and PWM approaches. For each of the three modulation methods, the output voltages derived from the fundamental line voltage are a root three multiple of the fundamental phase voltage.

The basic output peak load current in the SVPWM technique is equal to 25% more than in the SPWM technique and 60% more than in the PWM approach, as shown in Table 1 above. The Total Harmonic Distortion (THD) of the fundamental output load current is about equal to 25% for SPWM and 70% for PWM when comparing SVPWM to SPWM and PWM.

Table 1. Representation of the THD and load current values corresponding to each switching frequency

S. No	Switching frequency value in khz	Output Current with SVPWM in Amps	THD Value with SVPWM in %	Output Current with SPWM in Amps	THD Value with SPWM in %	Output Current with PWM in Amps	THD Value with PWM in %
1	2	40.2	2.17	30	10	15	68.72
2	3	40.2	2.0	30	8.2	15	52.12
3	5	40.2	1.5	30	6.1	15	35.2
4	7	40.2	1.36	30	4.2	15	20.1
5	8	40.2	0.96	30	2.4	15	15.5

4.1 MATLAB/Simulink Results of the SVPWM Technique

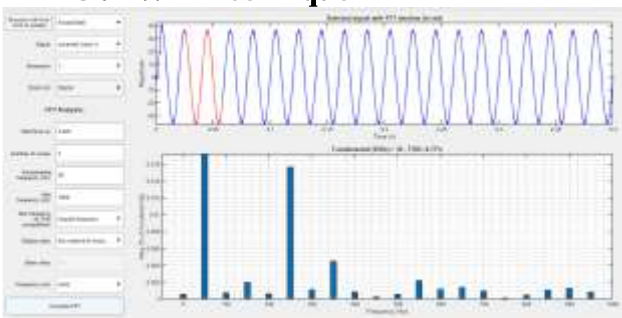

Fig. 5: FFT Analysis representation of the SVPWM technique

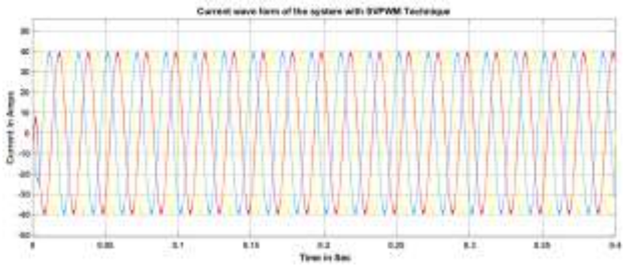

Fig. 6: Inverter output current waveform corresponding to the SVPWM technique

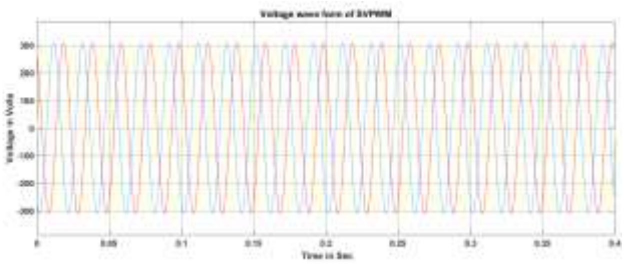

Fig. 7: Inverter output voltage waveform corresponding to the SVPWM technique SVPWM technique

Figure 5 shows the FFT analysis-related representation with the SVPWM technique and given the THD value of 2.17% with starting time at 0.025 sec, fundamental frequency of 50 Hz for 2 cycles. Figure 6 shows the output three-phase current of the inverter with an average value of 40 Amps. Figure 7 represents the output voltage of the three-phase inverter with the value of 300 volts.

4.2 MATLAB/Simulink Results of SPWM Technique

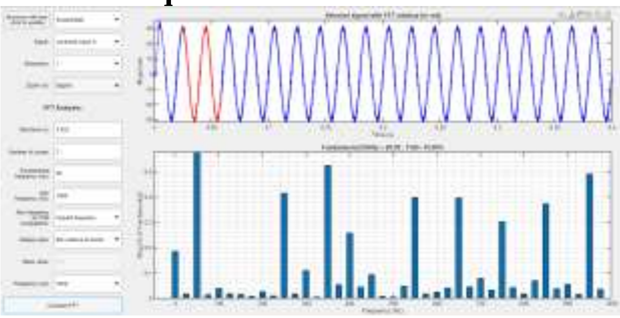

Fig. 8: FFT Analysis representation of the SPWM technique

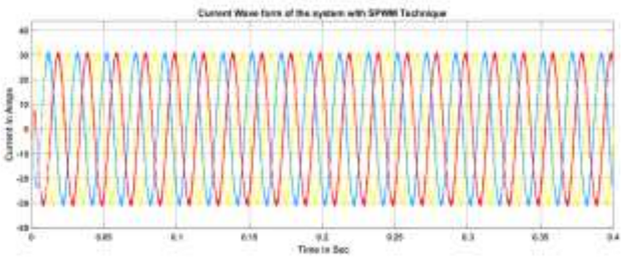

Fig. 9: Inverter output current waveform corresponding to the SPWM technique

Using the SPWM technique and a THD value of 10.00%, Figure 8 illustrates the description of the FFT analysis for two cycles at a fundamental frequency of 50 Hz and a starting time of 0.025 seconds. The inverter's output three-phase current, with an average value of 30 Amps, is displayed in Figure 9.

4.3 MATLAB/Simulink Results PWM Technique

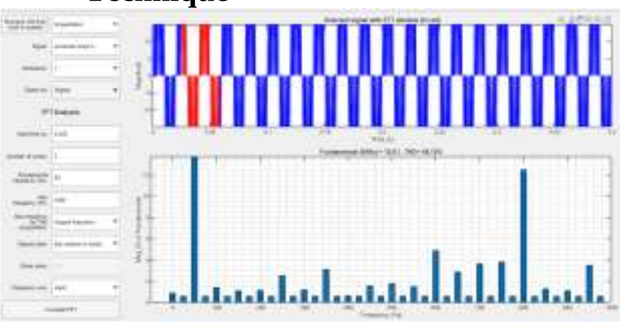

Fig. 10: FFT Analysis representation of the PWM technique

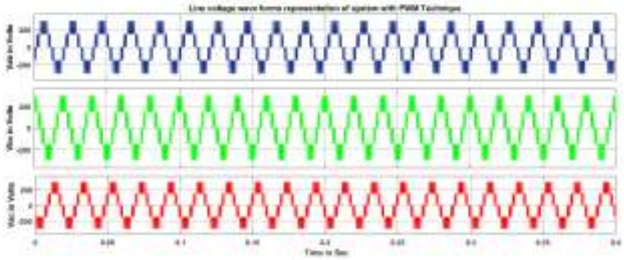

Fig. 11: Inverter output voltage waveform corresponding to the PWM technique

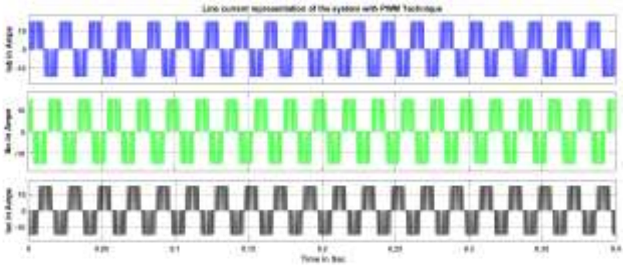

Fig. 12: Inverter output current waveform corresponding to the PWM technique

Figure 10 shows the FFT analysis for two cycles at a fundamental frequency of 50 Hz and a starting time of 0.025 seconds using the PWM approach with a THD value of 68.72%. Figure 12 shows the average three-phase current output of the inverter, which is 15 Amps. Figure 11 illustrates the three-phase inverter's 300-volt output voltage.

5 Conclusion

A comparison is made between the three approaches' performances. When compared to the SPWM and PWM techniques, MATLAB/Simulation demonstrates how well the SVPWM uses the DC bus voltage because its output is greater than that of the SPWM and PWM when measured using the fundamental output voltage. Superior outputs, higher efficiency, and less THD are achieved by Space Vector Pulse Width Modulation in comparison to PWM and Sinusoidal Pulse Width Modulation inverters operating at different switching frequencies.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

The authors equally contributed to the present research, at all stages from the formulation of the problem to the final findings and solution.

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Conflict of Interest

The authors have no conflicts of interest to declare.