

Design and Implementation of Carrier Based Sinusoidal PWM (Bipolar) Inverter

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Abstract: SPWM or sinusoidal pulse width modulation is widely used in power electronics to digitize the power so that a sequence of voltage pulses can be generated by the on and off of the power switches. The pulse width modulation inverter has been the main choice in power electronic for decades, because of its circuit simplicity and rugged control scheme SPWM switching technique is commonly used in industrial applications SPWM techniques are characterized by constant amplitude pulses with different duty cycle for each period. The width of this pulses are modulated to obtain inverter output voltage control and to reduce its harmonic content. Sinusoidal pulse width modulation or SPWM is the mostly used method in motor control and inverter application. In this development a unipolar and bipolar SPWM voltage modulation type is selected because this method offers the advantage of effectively doubling the switching frequency of the inverter voltage, thus making the output filter smaller, cheaper and easier to implement. Conventionally, to generate this signal, triangle wave as a carrier signal is compared with the sinusoidal wave, whose frequency is the desired frequency. In this paper single-phase inverters and their operating principles are analyzed in detail. The concept of sinusoidal Pulse Width Modulation (PWM) for inverters is described with analyses extended to different kinds of SPWM strategies. Finally the simulation results for a single-phase inverter (Bipolar) using the SPWM strategies described are presented [1],[2],[5]. This project deals with implementing the basic theory of a Sinusoidal Pulse Width Modulated Inverter (SPWM) technique for Bipolar voltage switching, its Simulink modelling, estimating various designing parameters. The project will be commenced by a basic understanding of the circuitry of the SPWM Inverter, the components used in its design and the reason for choosing such components in this circuitry. After this, it will be attempted to simulate a model circuit on any simulating software e.g. MATLAB and analyse the output waveforms and also varying the modulation index (M) for both Simulink Model and Implemented Design of Bipolar voltage switching

Keywords: Modulation, SPWM, Unipolar, Bipolar

1. Introduction

The dc-ac converter, also known as the inverter, converts dc power to ac power at desired output voltage and frequency. The dc power input to the inverter is obtained from an existing power supply network or from a rotating alternator through a rectifier or a battery, fuel cell, photovoltaic array or magneto hydrodynamic generator. The filter capacitor across the input terminals of the inverter provides a constant dc link voltage. The inverter therefore is an adjustable-frequency voltage source. The configuration of ac to dc converter and dc to ac inverter is called a dc-link converter. [2] Inverters can be broadly classified into two types, voltage source and current source inverters. A voltage-fed inverter (VFI) or more generally a voltage-source inverter (VSI) is one in which the dc source has small or negligible impedance. The voltage at the input terminals is constant. A current-source inverter (CSI) is fed with adjustable current from the dc source of high impedance that is from a constant dc source [2], [1], [6].

A voltage source inverter employing thyristor as switches, some type of forced commutation is required, while the VSIs made up of using GTOs, power transistors, power MOSFETs or IGBTs, self commutation with base or gate drive signals for their controlled turn-on and turn-off. A

standard single-phase voltage or current source inverter can be in the half-bridge or full-bridge configuration. The single-phase units can be joined to have three-phase multiphase topologies. Some industrial applications of inverters are for adjustable-speed ac drives, induction heating, standby aircraft power supplies, UPS (uninterruptible power supplies) for computers, HVDC transmission lines, etc [1],[8].

1.1 Inverters :

A device that converts DC power into AC power at desired output voltage and frequency is called an Inverter. Phase controlled converters when operated in the inverter mode are called line commutated inverters. But line commutated inverters require at the output terminals an existing AC supply which is used for their commutation. This means that line commutated inverters can't function as isolated AC voltage sources or as variable frequency generators with DC power at the input. Therefore, voltage level, frequency and waveform on the AC side of the line commutated inverters can't be changed. On the other hand, force commutated inverters provide an independent AC output voltage of adjustable voltage and adjustable frequency and have therefore much wider application.

Inverters can be broadly classified into two types based on their operation:

- Voltage Source Inverters(VSI)
- Current Source Inverters(CSI)

Voltage Source Inverters is one in which the DC source has small or negligible impedance. In Other words VSI has stiff DC voltage source at its input terminals. A current source inverter is fed with adjustable current from a DC source of high impedance, i.e. from a stiff DC current source. In a CSI fed with stiff current source, output current waves are not affected by the load. From view point of connections of semiconductor devices, inverters are classified as under [1], [2]

- Bridge Inverters
- Series Inverters
- Parallel Inverter

Bridge Inverters are classified as Half bridge & Full bridge

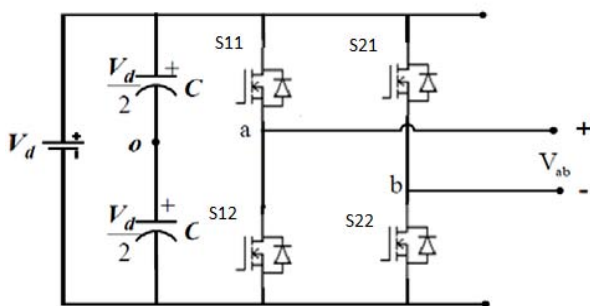


Figure 1: Schematic of a Single Phase Full- Bridge Inverter

A single-phase inverter in the full bridge topology is as shown in Fig. 1 which consists of four switching devices, two of them on each leg. The full-bridge inverter can produce an output power twice that of the half-bridge inverter with the same input voltage. The S PWM switching schemes are discussed in this section, which improve the characteristics of the inverter. The objective is to add a zero sequence voltage to the modulation signals in such a way to ensure the clamping of the devices to either the positive or negative dc rail; in the process of which the voltage gain is improved, leading to an increased load fundamental voltage, reduction in total current distortion and increased load power factor. In Fig. 1, the top devices are assigned to be S11 and S21 while the bottom devices as S12 and S22, the voltage equations for this converter are as given in the following equations.[1],[6].

$$\frac{V_d}{2} (S_{11}-S_{12}) = V_{an} + V_{no} = V_{ao} \quad \dots (1)$$

$$\frac{V_d}{2} (S_{21}-S_{22}) = V_{bn} + V_{no} = V_{bo} \quad \dots (2)$$

$$V_{ab} = V_{an} - V_{bn} \quad \dots (3)$$

The voltages Van and Vbn are the output voltages from phases A and B to an arbitrary point n, Vno is the neutral voltage between point n and the mid-point of the DC source. The switching function of the devices can be approximated by the Fourier series to be equal to 1/2 * M. Where M is the modulation signal which when compared with the triangular waveform yields the switching pulses Thus from Equations1,

2, and 3 the expressions for the modulation signals are obtained as

$$M_{11} = \frac{2(V_{an} + V_{no})}{V_d} \quad \dots (4)$$

$$M_{21} = \frac{2(V_{bn} + V_{no})}{V_d} \quad \dots (5)$$

Equations 4 and 5 give the general expression for the modulation signals for single-phase dc-ac converters. The various types of modulation schemes presented in the literature can be obtained from these equations using appropriate definition for Van, Vbn & Vno[1]

2. SPWM Switching Techniques

- PWM with Bipolar voltage switching
- PWM with Unipolar voltage switching.

SPWM with Bipolar Switching:

The basic idea to produce PWM Bipolar voltage switching signal is shown in Fig. 2. It comprises of a comparator used to compare between the reference voltage waveform Vr with the triangular carrier signal Vc and produces the bipolar switching signal. If this scheme is applied to the full bridge single phase inverter as shown in Fig., all the switch S11, S21, S12 and S22 are turned on and off at the same time. The output of leg A is equal and opposite to the output of leg B [3]

The output voltage is determined by comparing the reference signal, Vr and the triangular carrier signal, Vc and S12, S22 are turned on or turned off at the same time. The output of leg A is equal and opposite to the output of leg B. The output voltage is determined by comparing the control signal, Vr and the triangular signal, Vc as shown in Fig. 5 to get the switching pulses for the devices, and the switching pattern and output waveform is as follows.[2]

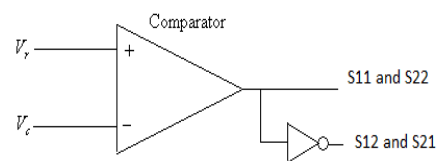


Figure 2: Bipolar Generator

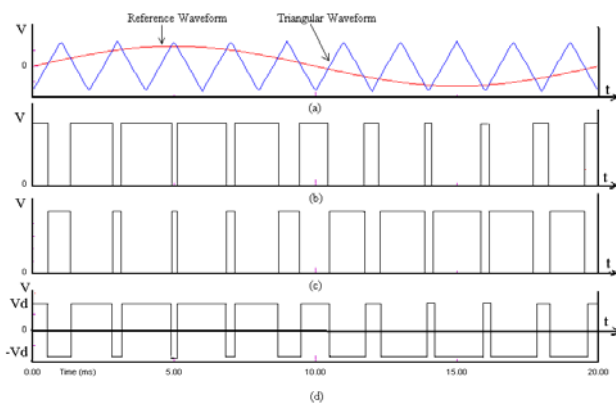


Figure 3: SPWM with Bipolar voltage switching (a) Comparison between reference Waveform and triangular waveform (b) Gating pulses for S11 and S22 (c) Gating pulses for S12 and S21 (d) Output waveform

2.2 SPWM with Unipolar Switching:

In this scheme, the triangular carrier waveform is compared with two reference signals which are positive and negative signal. The basic idea to produce SPWM with unipolar voltage switching is shown in Fig. 4. The different between the Bipolar SPWM generators is that the generator uses another comparator to compare between the inverse reference waveform $-V_r$. The process of comparing these two signals to produce the unipolar voltage switching signal. The switching pattern and output waveform is as follows in Fig. 5. In Unipolar voltage switching the output voltage switches between 0 and V_{dc} , or switching event is halved in the unipolar case from $2V_{dc}$ to V_{dc} . The effective switching frequency is seen by the load is doubled and the voltage pulse amplitude is halved. Due to this, the harmonic content of the output voltage waveform is reduced compared to bipolar switching. In Unipolar voltage switching scheme also, the amplitude of the significant harmonics and its sidebands is much lower for all modulation indexes thus making filtering easier, and with its size being significantly smaller between 0 and $-V_{dc}$. This is in contrast to the bipolar switching strategy in which the output swings between V_{dc} and $-V_{dc}$. As a result, the change in output voltage at each [2], [3], [4].

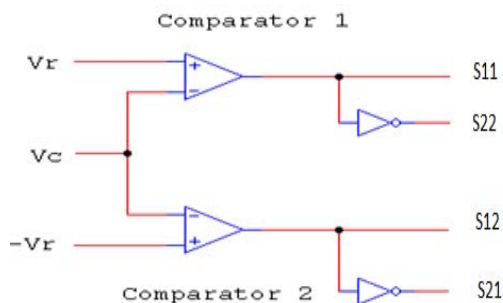


Figure 4: Unipolar PWM generator

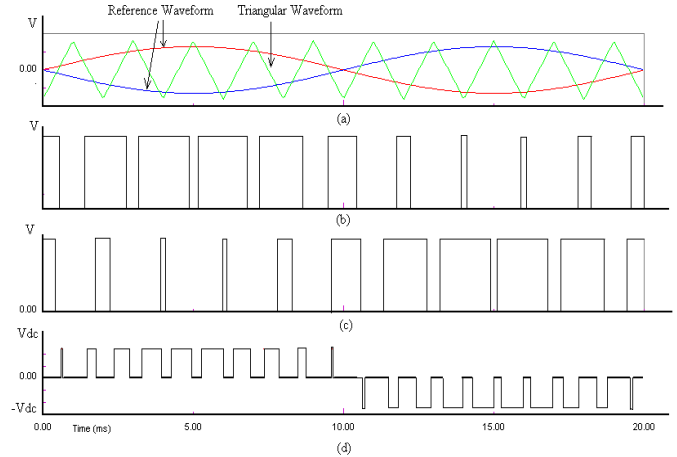


Figure 5: Waveform for SPWM with Unipolar voltage switching (a) Comparison between reference waveform and triangular waveform (b) Gating pulses for S11 and S22 (c) Gating pulses for S12 and S21 (d) Output waveform

3. Simulation and Implementation Results

Here we Design and Test Bipolar Voltage Switching for Variable Modulation Index and also simulate in MATLAB and see the switching pulses.

Simulink model and Waveforms:

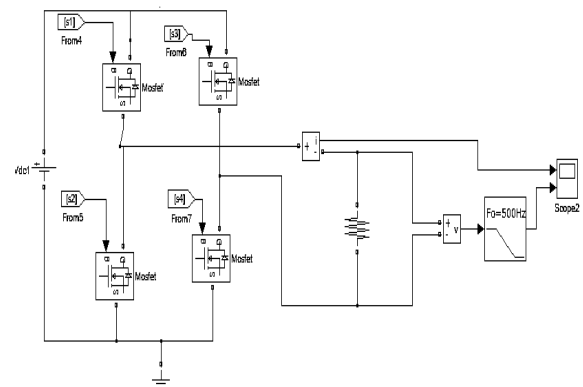


Figure 6: Simulink Model Bipolar Voltage Switching

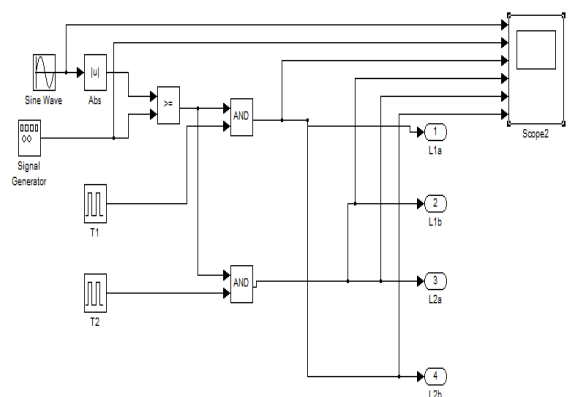


Figure 7: Simulink model for SPWN inverter

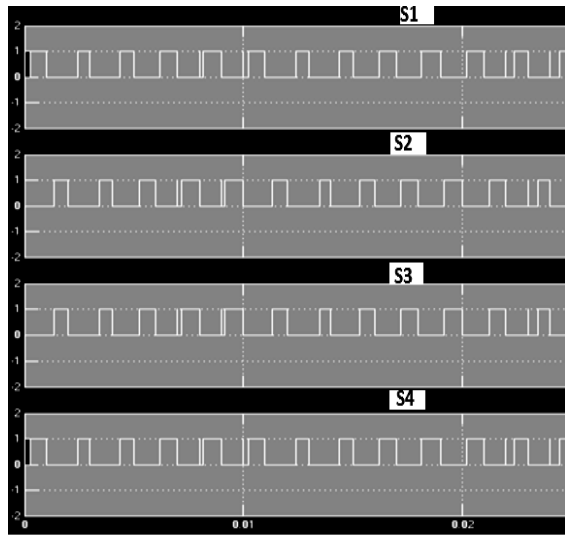


Figure 8: Gating pulses for S1, S2, S3 and S4

Table.1 Experimental result of Bipolar voltage switching for M=0.5

LOAD (W)	V_{in}	$I_{in}(A)$	P_{dc}	V_{out}	I_{out}	P_{ac}	%EFF.
100	12.2	6	73	227	0.31	66	90
160	12.0	10	123	223	0.45	99	81
200	12.0	14	168	220	0.58	129	76
300	12.0	22	264	220	0.91	203	77
400	12.0	26	312	221	1.32	290	93
500	12.0	30	360	220	1.54	388	94

4. Experimental kit and setup

Bipolar voltage switching inverter tested for different modulating index with different resistive loads.



Figure 9: Experimental setup with resistive load bank

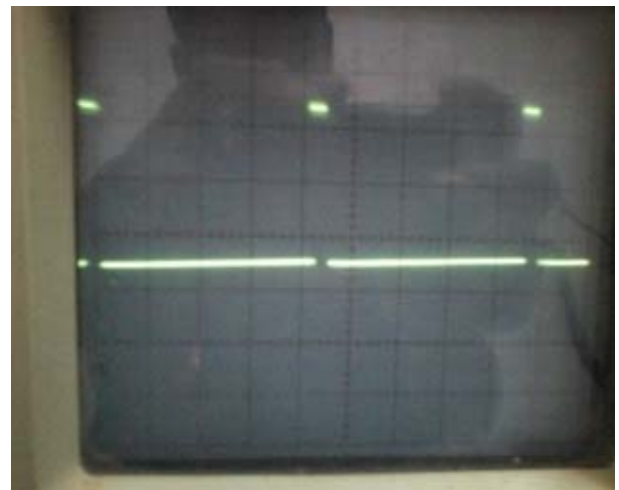


Figure.11 Switching gate pulses for Bipolar voltage switching when M=0.9

Table.2 Experimental result of Bipolar voltage switching for M=0.9

LOAD (W)	V_{in}	$I_{in}(A)$	P_{dc}	V_o	I_o	P_{ac}	%EFF.
100	12.0	8	96	220	0.31	68	81
160	12.0	11	132	221	0.45	99	76
200	12.0	13	156	219	0.58	127	80
300	11.0	20	221	223	0.91	202	91
400	11.0	28	336	221	1.32	291	86
500	11.0	35	387	220	1.48	325	84

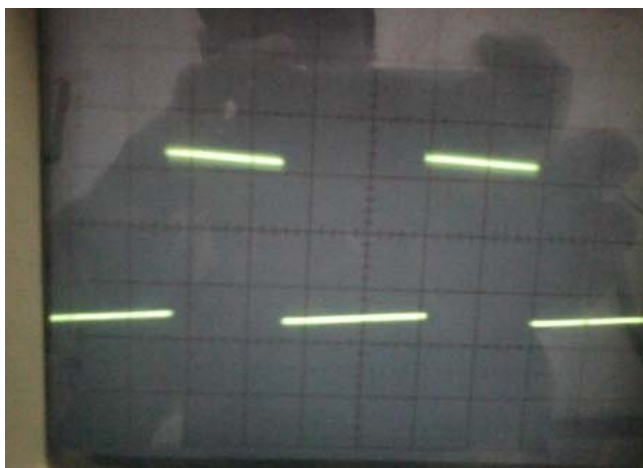


Figure.10 Switching gate pulses for Bipolar voltage switching when M=0.5

5. Conclusion

In this paper the single phase SPWM microcontroller-based 700VA inverter is designed and tested for Variable modulation index ($M=0.5-1.1$) For Bipolar voltage switching. It gives a different result of currents and voltages for different resistive loads with Variable modulation index and also note the gate pulse waveforms for different modulation index. It was found that it gives maximum efficiency for 100W load upto 92% for $M=0.7$ and simulate this Bipolar switching model in MATLAB, and note output waveform and gate pulses.

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