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Pulse-Width Modulated Inverters

IC 034 Power Electronics

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PULSE-WIDTH MODULATED INVERTERS

Objectives:
Study of Pulse-Width Modulated Inverter and study its characteristics using MATLAB

Introduction:
Inverters- They convert a dc input to a symmetric ac output voltage of desired magnitude and frequency.
In some cases, fixed(or non-controllable) input dc voltage is available and a variable ac output is desired. This can be attained by varying the gain of the inverter and is accomplished mostly by *Pulse Width Modulation(PWM)* control within the inverter.

Pulse width modulation control- In this method, a fixed dc input voltage is given to the inverter and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter components. This is the most popular method of controlling the output voltage and this method is termed as *pulse-width modulation* (PWM) control.

Inverters can be broadly classified into two types:
(a) Single phase inverters.
(b) Three phase inverters.
Ideally, the inverter output should be sinusoidal. But, in practical inverters the output is nonsinusoidal and contains certain harmonics.

A) **Single Phase Inverters:**
A.1) Principle of Operation:
The principle can be explained with Fig.(1a). Inverter ckt consists of 2 choppers. When transistor Q_1 is turned on for time $T_o/2$, the instantaneous voltage across load v_o is $V_s/2$. If transistor Q_2 only is turned on for time $T_0/2$,

$V_s/2$ apperas across the load. The logic circuit should be designed such that Q_1 and Q_2 should not be turned on at the same time. This inverter requires a three-wire dc source, and when a transistor is off, its resistive voltag is V_s instead of $V_s/2$. This inverter is known as *half bridge inverter.*

The rms output voltage V_0

$$\boxed{V_o = \left(\frac{2}{T_o}\int_0^{T_o/2}\frac{V_s^{\,2}}{4}dt\right)^{1/2} = \frac{V_s}{2}} \longrightarrow (1)$$

The instantaneous output voltage v_0

$$\boxed{\begin{aligned} v_o &= \sum_{n=1,3,5,\ldots}^{\infty}\frac{2V_s}{n\pi}\sin n\omega t \\ &= 0 \quad for\, n = 2, 4, \ldots \end{aligned}} \longrightarrow (2)$$

where, $\omega=2\pi f_0$ is the frequency of output voltage in rads per second.

For n=1, $\boxed{V_{o1} = 0.45}$

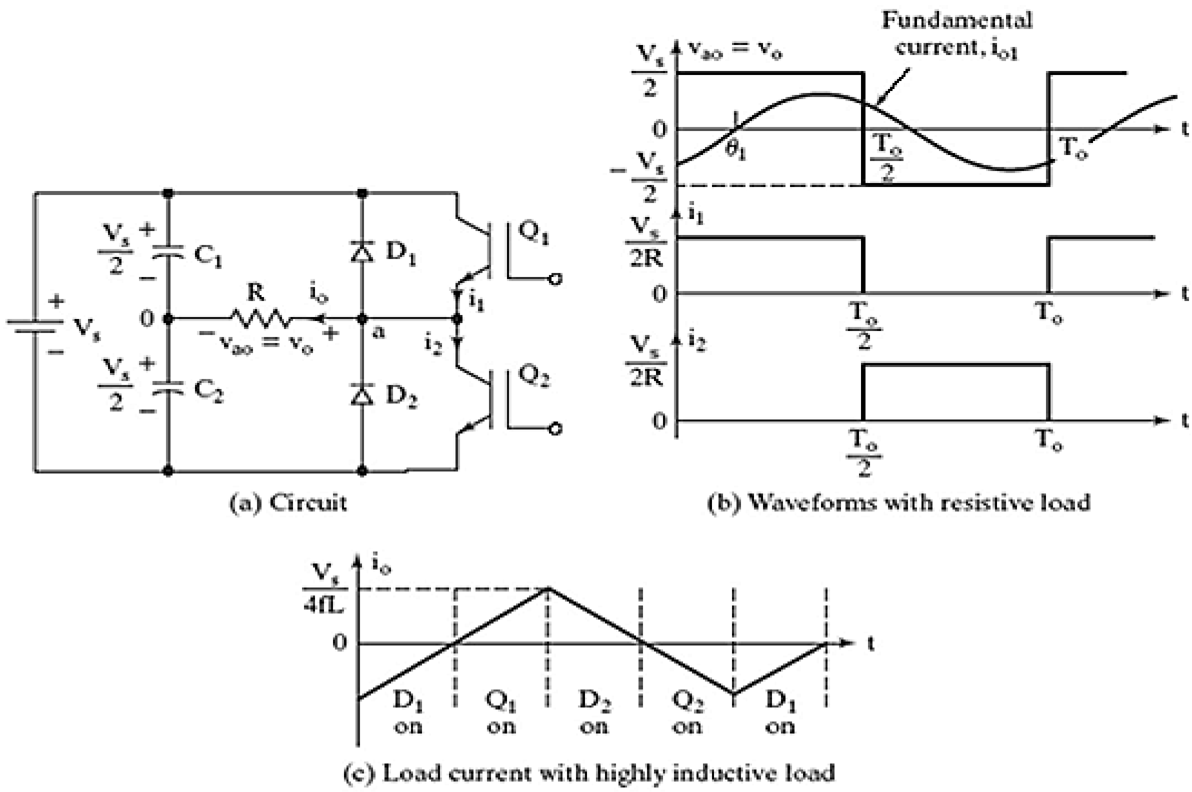


Fig.(1) Single Phase Half Bridge Inverter

A.2) <u>Performance Characteristics</u>:

1) *Total Harmonic Disortion(THD)*- It is the measure of closeness in shape between a waveform and its fundamental component.

$$\boxed{THD = \frac{1}{V_{o1}}\left(\sum_{n=2.3....}^{\infty} V_{on}^{2}\right)^{1/2}} \longrightarrow (3)$$

2) *Distortion Factor(DF)*- THD gives total harmonic content, but it does not indicate the level of each harmonic component. The DF indicates the amount of HD that remains in a particular waveform after the harmonics of that wave have been subjected to a second-order attenuation (i.e. divided by n^2). Thus. DF is a measure of affectiveness in reducing unwanted harmonics without having to specify the values of a second order load filter. It is defined as

$$\boxed{DF = \frac{1}{V_{o1}}\left(\sum_{n=2.3....}^{\infty} \left(\frac{V_{on}}{n^2}\right)^2\right)^{1/2}} \longrightarrow (4)$$

The DF of an individual (or n^{th}) harmonic component is defined as

$$\boxed{DF_n = \frac{V_{on}}{V_{o1}n^2} \qquad for\, n > 1} \longrightarrow (5)$$

B) <u>Single Phase Bridge Inverters</u>:

Inverter ckt consists of 4 choppers. When transistor Q_1 and Q_2 are turned on simultaneously, the input voltage V_s appears across the load. If the transistors Q_3 and Q_4 are turned on at the same time, the voltage across the load is reversed and is $-V_S$

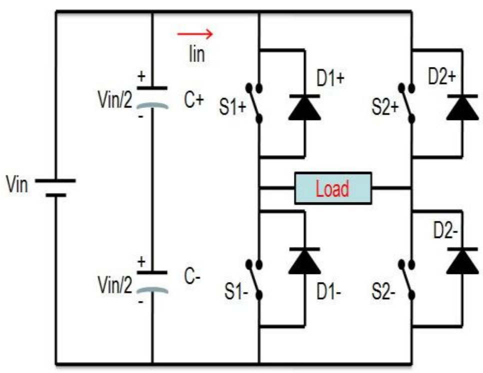
- <u>Rms Voltage-</u>

$$\boxed{V_o = \left(\frac{2}{T_o}\int_0^{T_o/2} V_S^2\right)^{1/2} = V_S} \longrightarrow (6)$$

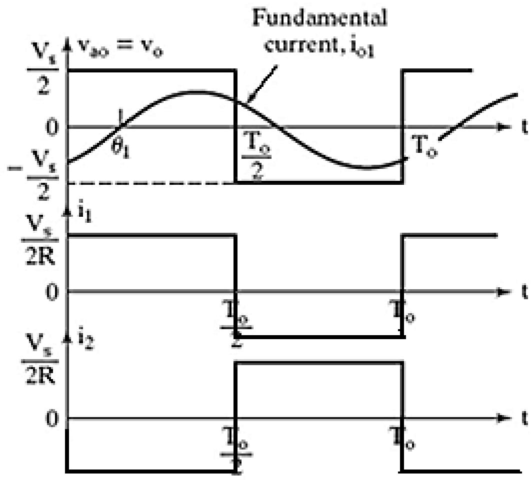
- Instantaneous Voltage-

$$\boxed{v_o = \sum_{n=1,3,5,\ldots}^{\infty} \frac{4V_s}{n\pi}\sin n\omega t} \longrightarrow (7)$$

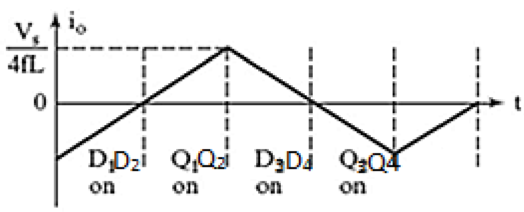
for n=1, V_1= $0.90V_S$



(a) Circuit



(b) Waveforms with resistive load



(c) Load current with highly inductive load

Fig.(2) Single Phase Full Bridge Inverter

B) **Three Phase inverters**:

They are normally used for high power applications. It consists of three single phase bridge inverters connected in parallel. The gating signal of single phase inverter should be advanced or delayed by 120^0 w.r.t. each other to obtain three phase balanced (fundamental) voltages.

If the output voltages of single phase inverters are not perfectly balanced in magnitudes and phases, the three phase output will also be unbalanced.

180° Conduction

- Three transistors ON at a time

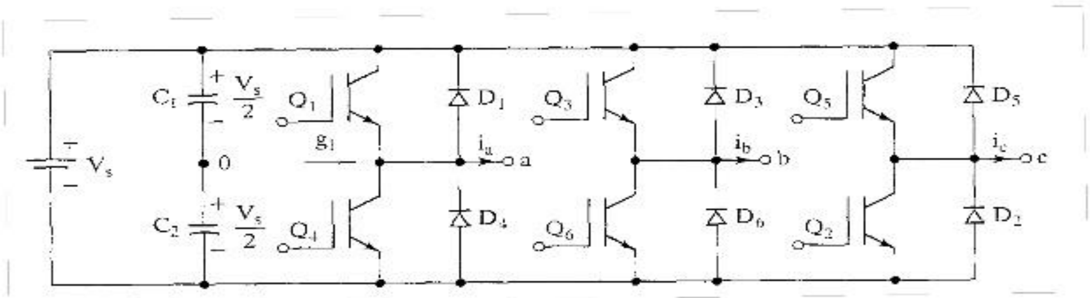


Fig.(3): Circuit Diagram of Three Phase Inverter at 180^0 conduction

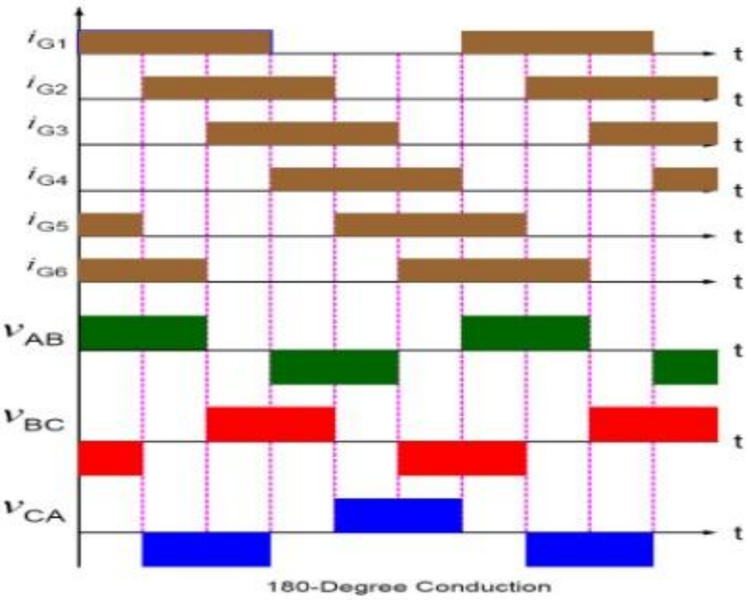


Fig.(4): Output Waveform of Three Phase Inverter at 180^0 conduction

Summary Table

TABLE 6.2 Switch States for Three-Phase Voltage-Source Inverter (VSI)

State	State No.	Switch States	v_{ab}	v_{bc}	v_{ca}
S_1, S_2, and S_6 are on and S_4, S_5, and S_3 are off	1	100	V_S	0	$-V_S$
S_2, S_3, and S_1 are on and S_5, S_6, and S_4 are off	2	110	0	V_S	$-V_S$
S_3, S_4, and S_2 are on and S_6, S_1, and S_5 are off	3	010	$-V_S$	V_S	0
S_4, S_5, and S_3 are on and S_1, S_2, and S_6 are off	4	011	$-V_S$	0	V_S
S_5, S_6, and S_4 are on and S_2, S_3, and S_1 are off	5	001	0	$-V_S$	V_S
S_6, S_1, and S_5 are on and S_3, S_4, and S_2 are off	6	101	V_S	$-V_S$	0
S_1, S_3, and S_5 are on and S_4, S_6, and S_2 are off	7	111	0	0	0
S_4, S_6, and S_2 are on and S_1, S_3, and S_5 are off	8	000	0	0	0

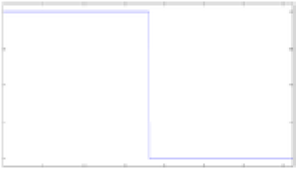
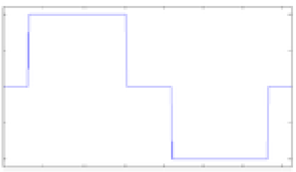
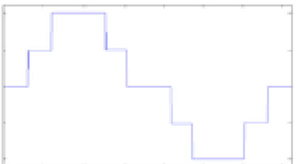
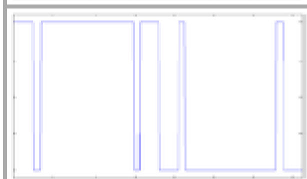
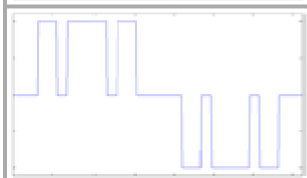
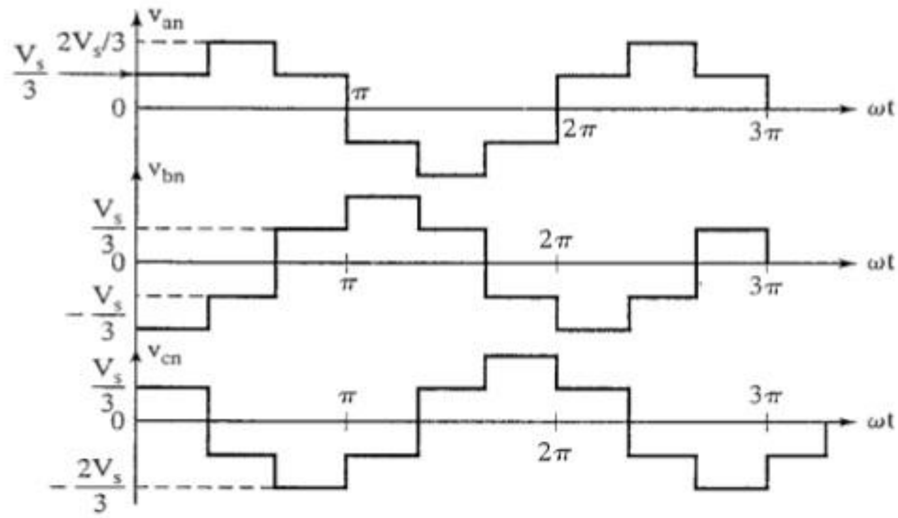
waveform	signal transitions per period	harmonics eliminated	harmonics amplified	System Description	THD
	2	-	-	2-level square wave	~45%[7]
	4	3, 9, 27,...	-	3-level "modified square wave"	> 23.8%[7]
	8			5-level "modified square wave"	> 6.5%[7]
	10	3, 5, 9, 27	7, 11,...	2-level very slow PWM	
	12	3, 5, 9, 27	7, 11,...	3-level very slow PWM	

Fig.(5)

Phase Voltages for 180° Conduction



MATLAB Simulation:

Simulation done using SIMULINK.

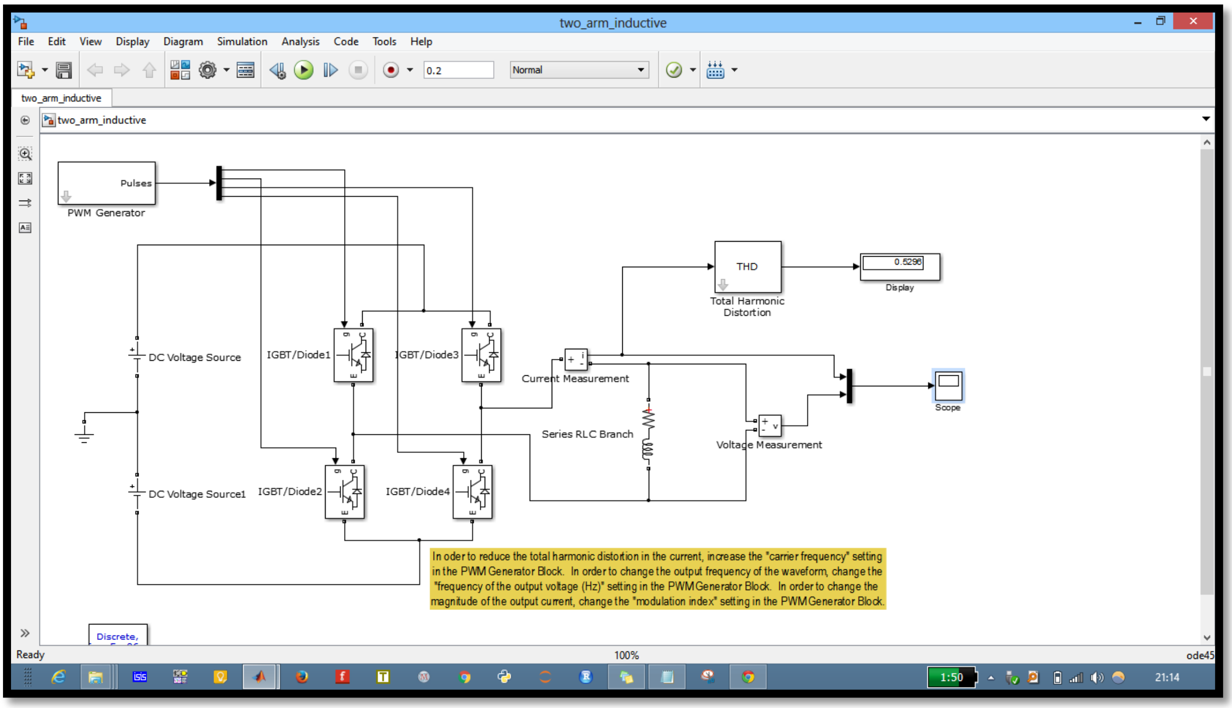


Fig.(6) Single Phase Bridge Inverter with THD

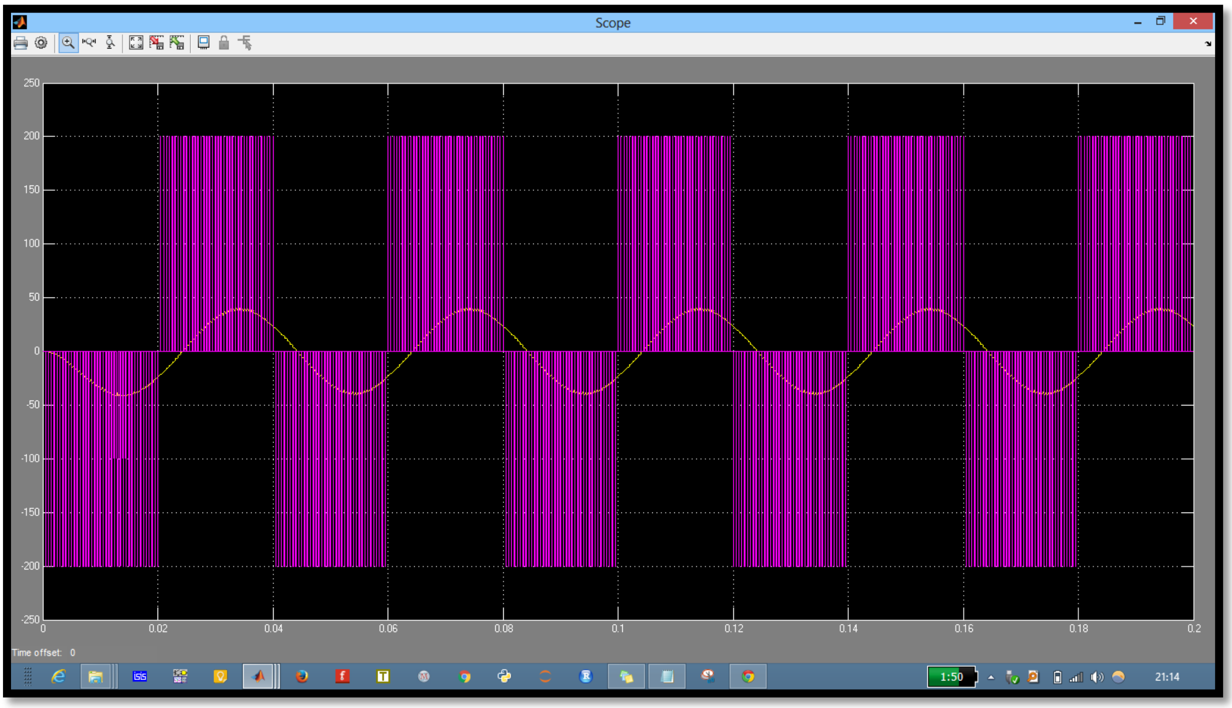


Fig.(7)Waveform of Single Phase Bridge Inverter with THD

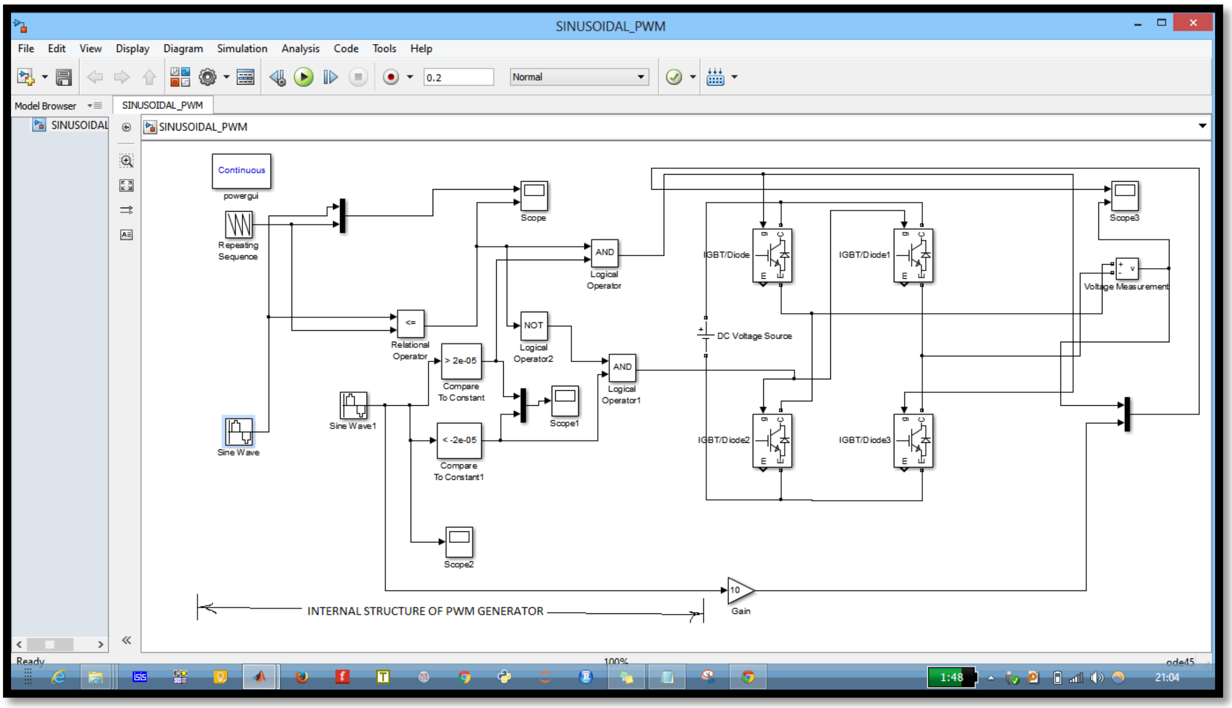


Fig.(8) Block Diagram of Sinusoidal PWM inverter

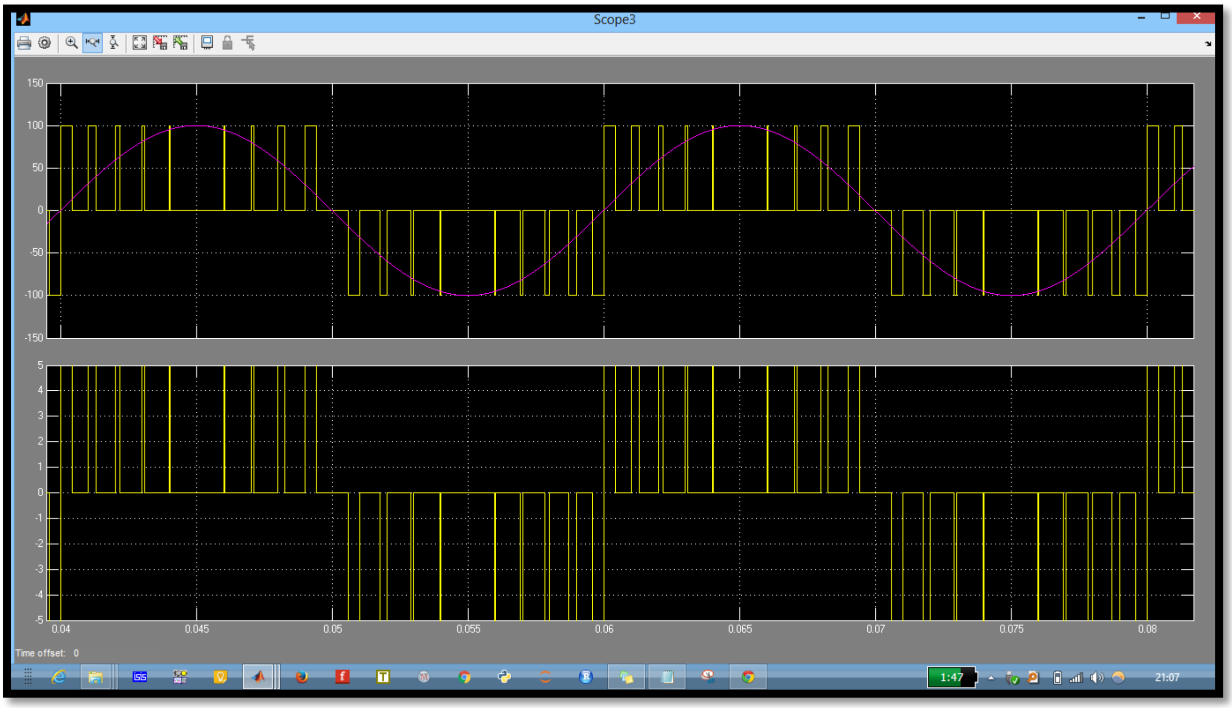


Fig.(9) Waveform of Sinusoidal PWM inverter

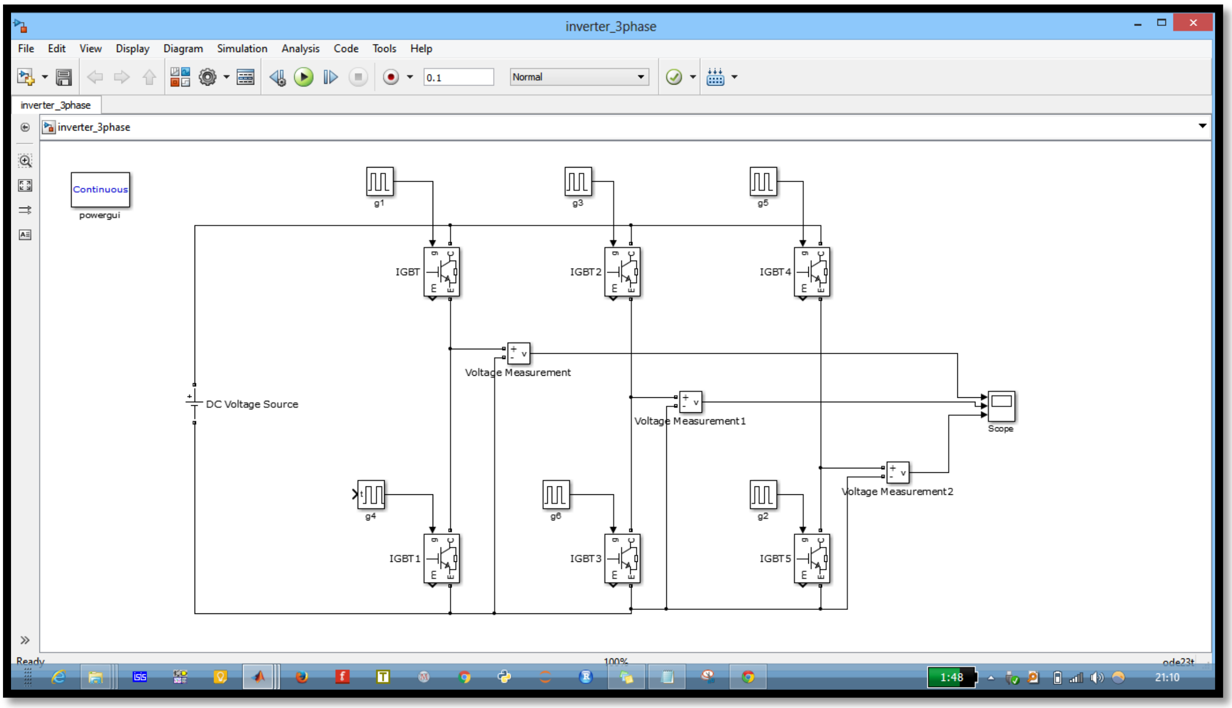


Fig.(10) Block Diagram of 3-Phase Inverter at 180^{0} conduction mode

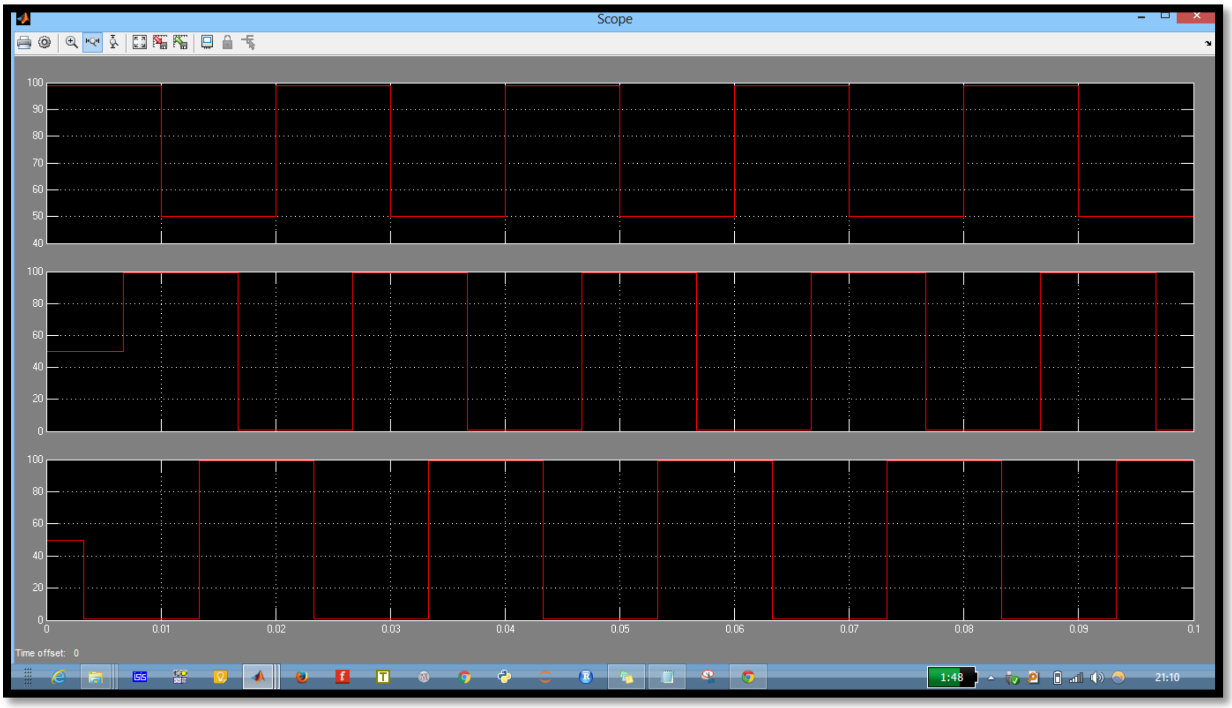


Fig.(11) Waveform of 3-Phase Inverter at 180^{0} conduction mode

<u>Description of the commonly used blocks in simulation</u>:

1. <u>Powergui:</u>

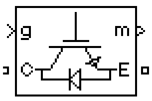
The Powergui block allows you to choose one of the following methods to solve your circuit:

- Continuous, which uses a variable step solver from Simulink
- Ideal Switching continuous
- Discretization of the electrical system for a solution at fixed time steps
- Phasor solution

The Powergui block is necessary for simulation of any Simulink model containing SimPowerSystems blocks. It is used to store the equivalent Simulink circuit that represents the state-space equations of the model. There are three types of Powergui models named as discrete, continuous and phasor. We select each on the basis of our application.

2. <u>IGBT/Diode</u>:

The IGBT/Diode block is a simplified mode of an IGBT (or GTO or MOSFET)/Diode pair where the forward voltages of the forced-commutated device and diode are ignored.



3. <u>PWM Generator</u>:

The PWM Generator block generates pulses for carrier-based pulse width modulation (PWM) converters using two-level topology. The block can be used to fire the forced-commutated devices (FETs, GTOs, or IGBTs) of single-phase, two-phase, three-phase, two-level bridges or a combination of two three-phase bridges. The pulses are generated by comparing a triangular carrier waveform to a reference modulating signal. The modulating signals can be generated by the PWM generator itself, or they can be a vector of external signals connected at the input of the block. One reference signal is needed to generate the pulses for a single- or a two-arm bridge, and three reference signals are needed to generate the pulses for a three-phase, single or double bridge. The amplitude (modulation), phase, and frequency of the reference signals are set to control the output voltage (on the AC terminals) of the bridge connected to the PWM Generator block. The two pulses firing the two devices of a given arm bridge are complementary. The following figure displays the two pulses generated by the PWM Generator block when it is programmed to control a one-arm bridge.

Conclusion:

Widely used in industries as variable speed ac motors drives, induction heating, standby power supplies, and uninterrupted power supplies.

- Typical single phase outputs are 120 V at 60 Hz, 220 V at 50 Hz, 115V at 400 Hz.
- For high power three phase systems, it is 220 to 380 V at 5 Hz, 120 to 208 at 60 Hz, 115 to 200 V at 400 Hz.

References:

- MUHAMMAD H. RASHID, *Power Electronics, Circuits, Devices and Applications,* 3rd Edition, Pearson Education, Inc, New Delhi 2004
- P.S. BIMBHRA, *Power Electronics,* 4th Edition, Khanna Publishers, Delhi 2006
- Official MATLAB website: *in.mathworks.com*
- For Images: Google.

Thank You

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