

SIMULATION OF SINGLE PHASE H-BRIDGE INVERTER TO AVOID COMPLEX BEHAVIOUR

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Abstract-Nonlinear phenomena investigated through simulation on Single phase fully controlled H-bridge inverter in this paper. This paper is proposed to use MATLAB/Simulink software to design, analysis and evaluation of single phase power electronic inverter performance on different loads condition. Appropriate conducting angles with suitable delays are applied for controlling the switching of the switches of inverter by a simple control strategy. In this paper Load is consider as bifurcation parameter so by changing it system run towards chaos side from smooth side.

In this paper firstly the circuit is modeled with Simulink then result ant output voltage and current waveforms at different loads are analyzed hence the distorted output waveforms is also shown so that can be studied to find out the instability in the circuit. The simulation response shows the operation of single phase h- bridge inverter and also nonlinearities at different loads. It is observed that the inverter turns from periodic operation to chaotic operation as the loads are changed .The waveforms obtained by simulation indicates that the inverter shifts from period one to chaos as the circuit parameters varied. This information is useful for designing hardware circuits in area of power electronics.

Keywords: *single-phase full-bridge inverter; matlab/Simulink; semiconductor switch; nonlinear loads*

I. INTRODUCTION

Power electronics converters may be termed as nonlinear time-varying dynamical systems due to wealth of nonlinear phenomena, including various kinds of chaos associate with them. The principal source of non-linearity is the inherent switching action and presence of nonlinear components (e.g. the diodes) and control methods (e.g. pulse-width modulation). These nonlinearities are a major source of engineering malfunction. In order to avoid these phenomena it is very important to identify and analyze the nonlinearities of a converter. A desired ac output power from input DC power at desired magnitude of output voltage and frequency can be obtained by using an inverter. This conversion can be obtained either by controlled switch on and switch off devices (e.g. BJT, MOSFET, IGBT, and MCT etc.) or by using forced commutated thyristors, depending on application. The output voltage waveform across load of an ideal inverter should be pure sinusoidal. The voltage waveforms of practical inverter are however, non-sinusoidal and contain few harmonics. Non-sinusoidal Square wave or quasi-square wave voltage maybe acceptable for small and medium power application and for large power application small distorted, sinusoidal waveform are required. The output frequency is determined by the rate at which the semiconductor switches are turned on and turned off of an inverter by the inverter control scheme and consequently, a variable frequency AC output is readily provided. The harmonics content of output

voltage can be minimized or decreased significantly by switching technique of variable high speed power semiconductor switches.

The applied DC supply input to the inverter maybe through battery, fuel cell, solar PV cell or other DC supply source. But in most applications of industries, it is fed by an ac to dc converter. This arrangement of AC to DC converter and DC to AC inverter is called a DC link at circuit frequency is rectified and then filtered by filtering process in the DC link before being invert to AC at flexible frequency. Rectification is obtained by standard semiconductor diode or thyristors converter circuits and inversion is achieved by the circuit techniques.

The term H-Bridge is obtained from the typical configuration representation of such a circuit shown in figure 1. An h-bridge is built with four switches (solid-state). When the switches S_1 and S_2 (according to the figure1) are closed (and S_3 and S_4 are open) a positive voltage will be applied across the load. By opening S_1 and S_2 switches and closing S_3 and S_4 switches, this voltage is reversed, allowing reverse operation of the Circuit. Using the nomenclature above, the switches S_1 and S_4 should never be closed at the same time, as this would create a short circuit on the input supply voltage source. The same applies to the remaining other switches S_2 and S_3 . This condition is known as shoot-through. A power electronics converter may needs two, four or more semiconductor devices depending upon the circuit configuration. For e.g. Single phase half bridge inverter require a power module consisting of two power semiconductor devices; a full converter (or h-bridge converter) require a power module having four semiconductor devices; Three phase full converter needs a power module having six semiconductor switching devices.

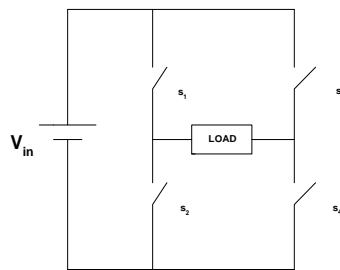


Figure: 1 Circuit of H-bridge inverter

The word ‘inverter’ in the context of power-electronics converter denotes a class of power conversion (or power conditioning) circuits that operates from a dc supply voltage source or a dc supply current source and converts it directly into ac voltage or current. The ‘inverter’ does opposite of what ac-to-dc ‘converter’ does. Even though input to an inverter circuit is a dc supply source, it is not uncommon to have this dc obtained from an ac supply source such as utility ac supply. Thus, for example, the primary supply source of input power may be used as ac voltage supply that is changed to dc through an ac to dc converter and after that ‘inverted’ return to ac using an inverter. Here, the final ac output may be of a changed frequency and magnitude than the input ac of the utility supply. There are various applications of inverters such as adjustable-speed ac motor drives, uninterruptible power supply, and running ac appliances from an automobile battery etc. complex behavior shown in this dc to ac converter system by taking load as bifurcation parameter. Therefore as load changes converter moves from smooth operation mode to chaotic mode of operation occurs due to nonlinearities in system.

II. SYSTEM DESCRIPTION OF SINGLE PHASE FULL BRIDGE INVERTER

Single phase h-bridge inverter is shown in figure1. The inverter uses two pair of controlled switches (S_1S_2 and S_3S_4). The turn on device of one pair operate simultaneously in order to develop a positive voltage ($+V_0$) across the load, switch s_1 and s_2 are turned on simultaneously whereas to have negative voltage ($-V_0$) across the load, we need to turn-on the switches s_3 and s_4 .

A. OPERATION WITH RESISTIVE LOAD

Voltage and current waveform with resistive load are shown in figure given below. The bridge-inverter operates in two modes in one cycle of output.

- a) **Mode-1:** In this mode, switch S_1 and S_2 conducts simultaneously. The load voltage is $+V_0$. The equivalent circuit for mode-1 is shown in figure below in equivalent circuit, S_1 and S_2 are turned-off and S_3 and S_4 are turned-on.
- b) **Mode-2:** At $t=t/2$, switches S_3 and S_4 are turned-on and S_1 and S_2 are turned-off. The load voltage is $-V_0$. The switch, S_3 and S_4 are turned-off and S_1 and S_2 are turned-on again.

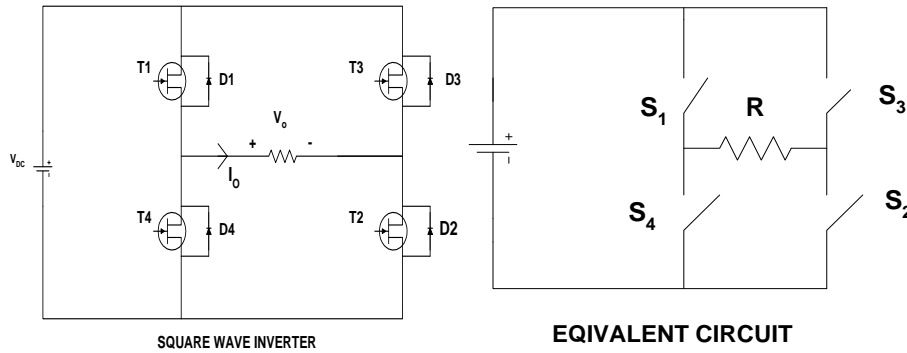


Figure2: Square wave inverter and its equivalent circuit

B. SQUARE-WAVE INVERTER WITH RL LOAD

When an inductive load presents some considerations in designing the switches in full bridge inverter circuit due to the switch current must be bidirectional.

At $t = 0$, Assumptions made: switch S1 & switch S2 are closed; switch S3 & switch S4 are opened.

Load voltage $V_o = + V_{dc}$

Current I increase in the load, switch S1 and switch S2. Current is expressed as sum of forced and natural responses.

$$I_o(t) = i_f(t) + i_n(t)$$

$$I_o(t) = V_{dc}/R + Ae^{-t/\tau} \quad , \quad 0 \leq t \leq T/2$$

Where

$I_f(t)$ = forced current;

$I_n(t)$ = natural current;

Where $\tau=L/R$, A =constant

a) At $t = T/2$ Assumptions made: S1 & S2 are opened, S3 & S4 are closed.

Load voltage $V_o = - V_{dc}$

$$I_o(t) = i_f(t) + i_n(t)$$

$$-V_{dc}/R + Be^{-(t-T/2)/\tau} \quad , \quad T/2 \leq t \leq T$$

$I_f(t)$ = forced current;

Table 1.1: Switching States of Single Phase Inverter

S ₁	S ₂	S ₃	S ₄	V _A	V _B
ON	OFF	ON	OFF	$\frac{V_S}{2}$	$-\frac{V_S}{2}$
OFF	ON	OFF	ON	$+\frac{V_S}{2}$	$+\frac{V_S}{2}$
ON	OFF	ON	OFF	$\frac{V_S}{2}$	$-\frac{V_S}{2}$
OFF	ON	OFF	ON	$-\frac{V_S}{2}$	$+\frac{V_S}{2}$

$I_n(t)$ = natural current ;

Where $\tau=L/R$, B =constant

III. BASIC PRINCIPLE

Under the assumption that the inductor current is essentially piecewise linear, the dynamics of the controlled current is described by the following map:

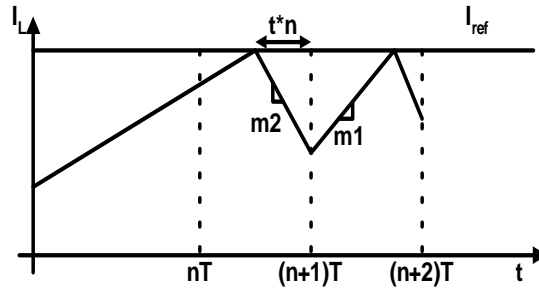


Figure 3: Inductor Current for abnormal behavior

$$I_{n+1} = I_n + m_1 T \quad \text{if } I_n \leq I_{ref} - m_1 T \quad (1)$$

$$I_{n+1} = I_{ref} - m_2 t_n \quad \text{if } I_n > I_{ref} - m_1 T \quad (2)$$

Where $I_n = I_L(nT)$ is the value of the inductor current at the clock instant nT ; m_1 and m_2 are respectively the magnitudes of the slopes on the increasing and decreasing segment of I_L and t_n is the duration of the OFF cycle in the clock in the cycle between nT and $nT + T$. Under steady state operation in periodic or chaotic mode, with a constant input voltage V_{in} and allow ripple output voltage of constant average value V_{out} , the constants m_1 , m_2 and α can be expressed as:

$$m_1 = \frac{V_{in} - V_{out}}{L} \quad \text{and} \quad m_2 = \frac{V_{out}}{L} \quad (3)$$

$$\alpha = (m_2 / m_1) = \frac{V_{out}}{V_{in} - V_{out}} \quad (4)$$

Here α is the ratio of slopes magnitude. If $\alpha > 1$, then state of operation of converter is unstable. Fig.2 shows a typical region of the inductor current, I_L , of a ac-dc converter under current mode control in the unstable region.

IV. MATLAB/SIMULINK

MATLAB/SIMULINK is a full-strength graphical user-interface to MATLAB which permits dynamic system to be described in a simple block diagram form. A library of function blocks, like sources, sinks, discrete, connections, linear, and non-linear can be used in the simulation. The power semiconductor device is normally simulated by the element switch, which is an element in non-linear function blocks. This paper is purposed to use MATLAB/Simulink software to design, analysis and evaluation of power electronic dc to ac converter on different load condition. Besides, it can show what differential in simulation of this software with others. For modeling, Simulink provides a graphical user interface (GUI) for building model as block diagram, using click-and-drag through mouse operation. Simulink includes a comprehensive block library of sink, sources, linear and nonlinear components and connectors. These are the main feature to customize and create useful block in this software tool.

After a model is defined, it can simulate, using a choice of integration methods, either from Simulink menus or by entering command in MATLAB's command window. In addition, the parameter can be changed and immediately see what happen for 'what if' exploration. In inverter full bridge inverter circuit, an AC output is synthesized from a DC input by closing and opening the switches in appropriate sequence or switching scheme. For that, the h-bridge technique is used in control the closing and opening switches. The switching control scheme for switches applied is not bipolar but it is unipolar. The PWM signal is used to limit ON/OFF switching position of the semiconductor switches (e.g. IGBTs) will functions in driver model that created to control the switching scheme. Then, the simulation is made from the dc to ac converter model in Simulink.

V. DETERMINATION OF SWITCHING ANGLES:

Phase delay

The delay before the pulse is generated specified in seconds if the pulse type is time-based or as number of sample times if the pulse type is sample-based. Here **the period is set at 0.02 sec.**

For phase delay Values can be obtained as follows

$$PHASE DELAY = \frac{FIRINGANGLE}{360^\circ} * TIME PEROD$$

For 50Hz frequency

$$T = \frac{1}{f} = 1/50 = 0.02 \text{ sec} = 20\text{ms}$$

Time period is 0.02ms. Therefore for delay switching angle for switch of converter

$$\text{Time Period } 0.02 \text{ sec} = 360^\circ$$

$$\text{So } 1^\circ = 0.02/360$$

$$\text{For } 60^\circ = (0.02/360) * 60$$

Source block parameters for pulse generator 1 and 2 are:

- Pulse type-Time based
- Period in seconds-0.02sec
- Pulse Width-40% of period
- Phase delay in seconds-0.0005sec.

Source block parameters for pulse generator 3 and 4 are:

- Pulse type-Time based
- Period in seconds-0.02sec
- Pulse Width-40% of period
- Phase delay in seconds-0.0105sec.

PHASE DELAYS FOR THREE LEVEL SINGLE PHASE H-BRIDGE INVERTER: These delay angles provided to pulse generator 1, 2 blocks for 3 level inverter.

$$\theta_1 = \text{Phase delay of S1,S3} = \frac{9^\circ}{360^\circ} * 0.02$$

$$\theta_1 = \text{Phase delay of S1,S3} = 0.0005$$

$$\theta_2 = \text{Phase delay of S2,S4} = \frac{189^\circ}{360^\circ} * 0.02$$

$$\theta_2 = \text{Phase delay of S2,S4} = 0.0105$$

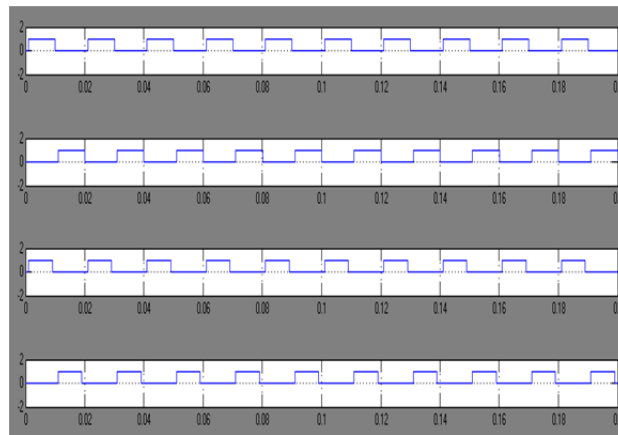


Figure 4: Switching pulses waveforms from S1 to S4 of H Bridge Inverter

A. MATLAB SIMULINK MODEL OF SINGLE PHASE INVERTER:

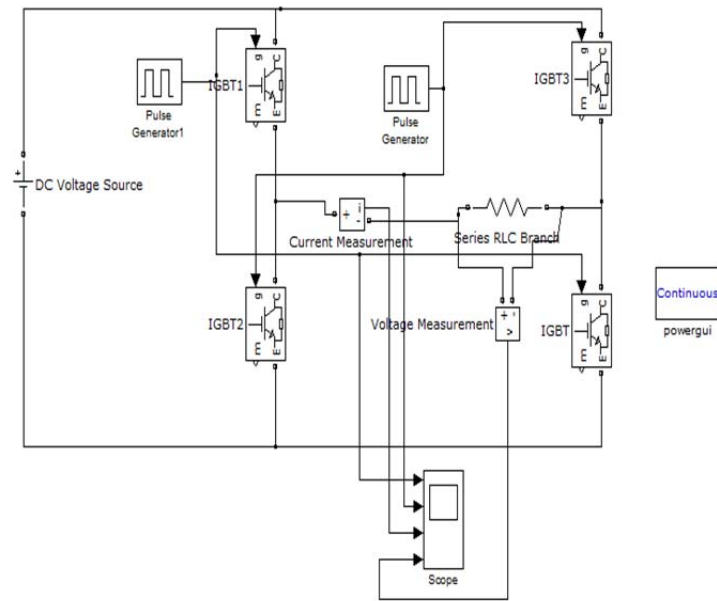


Figure 5: Simulink Model of H Bridge Inverter with R Load

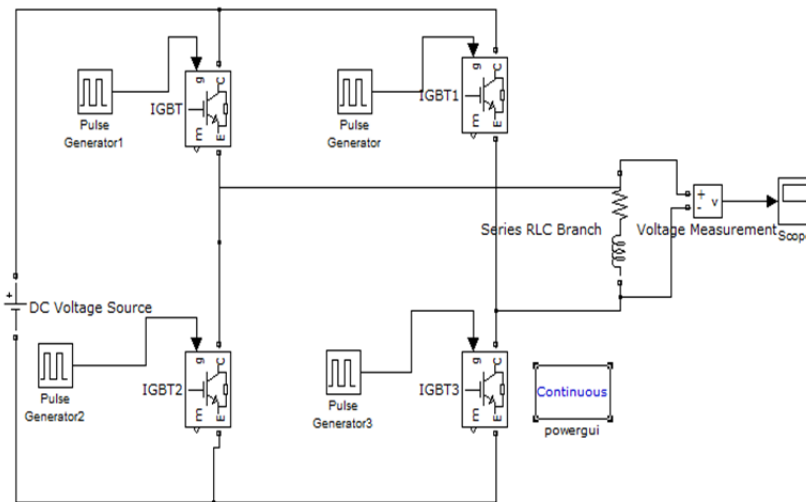


Figure 6: Simulink Model of H Bridge Inverter with RL Load

B. SIMULINK RESULTS:

The complete circuit of Fig.1 is simulated on the software MATLAB/SIMULINK. Figure 7 shows the voltage across load when load is purely resistive with input voltage 100V which is pure square wave. Figure 8 shows the voltage across load when load R-L type with input voltage 100V in which voltage waveform starts to move toward chaos operation. Figure 16 & 17 shows enlarge view of distorted V & I waveforms and also indicate that as bifurcation parameter changes to certain value then converter reaches to chaotic mode Fig.18 shows FFT analysis of single phase inverter with $R=100\Omega$, $L=0.2H$ when input voltage set at 100v.

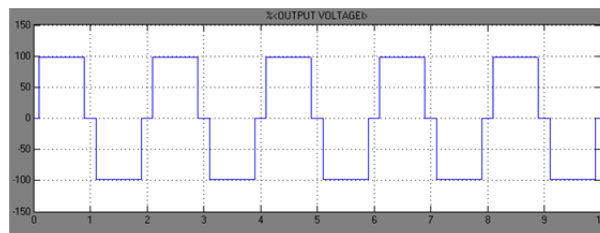


Figure 7: Output Voltage Waveform of H Bridge Inverter with R load (When $R=10\Omega$, $V_{dc}=100V$)

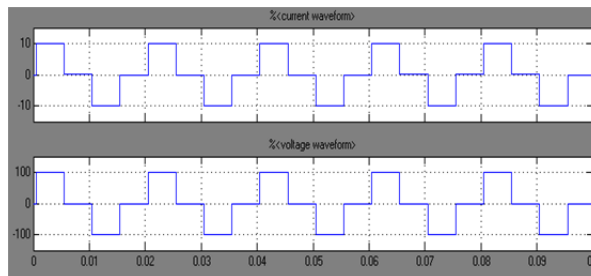


Figure 8: Output Voltage and current Waveform of H Bridge Inverter with R load (When $R=10\Omega$, $V_{dc}=100V$)

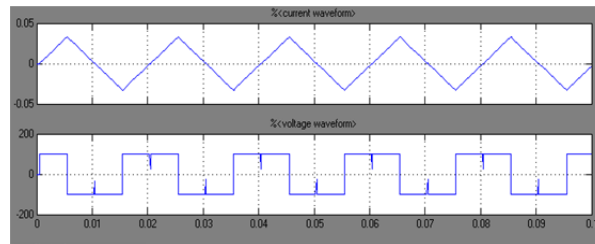


Figure 9: Output Voltage and current Waveform of H Bridge Inverter with RL load (When $R=10\Omega, L=15, V_{dc}=100V$)

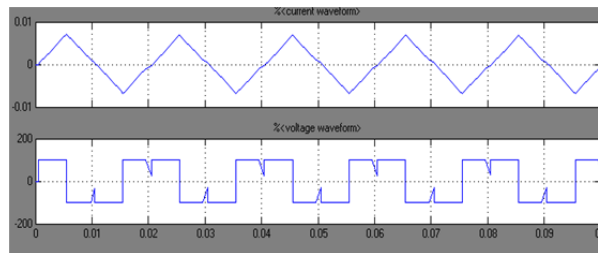


Figure 10: Distorted Output Voltage Waveform on R-L load (Distorted Output Voltage When $R=10\Omega, L=70H, V_{dc}=100V$)

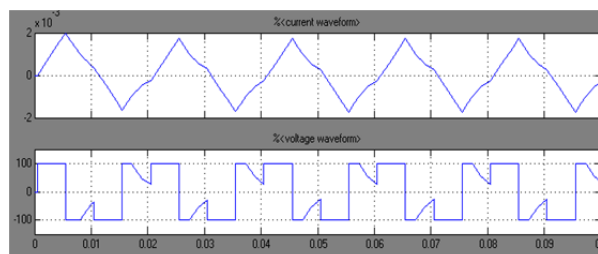


Figure 11: Output Voltage and Current Waveform of H Bridge Inverter with large RL load (Distorted Output Voltage When $R=10\Omega, L=250H, V_{dc}=100V$)

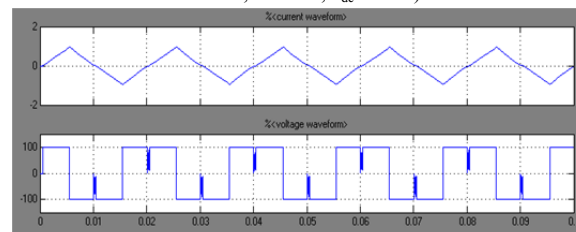


Figure 12: Output Voltage and Current Waveform of H Bridge Inverter with RL load (Distorted Output Voltage and Current When $R=10\Omega, L=0.5H$ and $V_{in}=100V$)

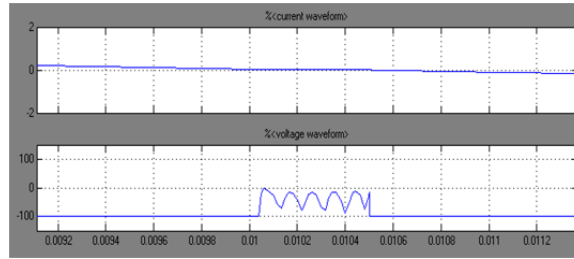


Figure 13: Enlarge view of output voltage and current waveform during distortion (Distorted Output voltage and current waveform when $R=100\Omega$, $L=0.2H$ and $V_{in}=100V$)

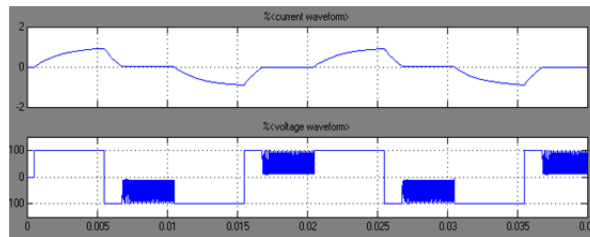


Figure 14: Output Voltage and Current Waveform of H Bridge Inverter with large RL load (Distorted Output Voltage and current When $R=100\Omega$, $L=.2H$, $V_{dc}=100V$)

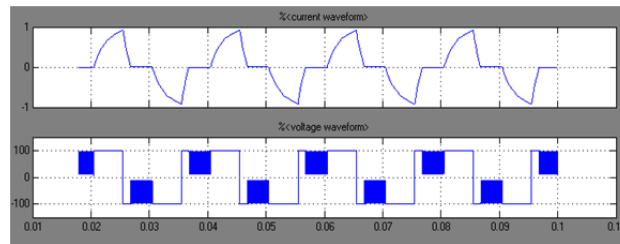


Figure 15: Output V and I Waveform of H Bridge Inverter with RL load (Distorted Output Voltage When $R=100\Omega$, $L=.2H$, $V_{dc}=100V$)

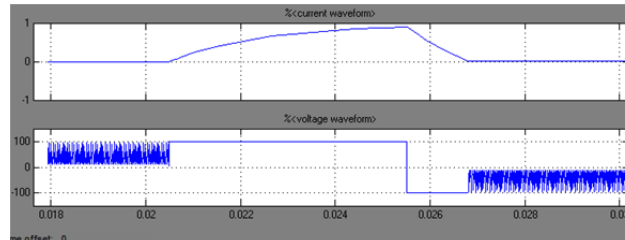


Figure 16: Enlarge view of output voltage and current waveform of above fig.15

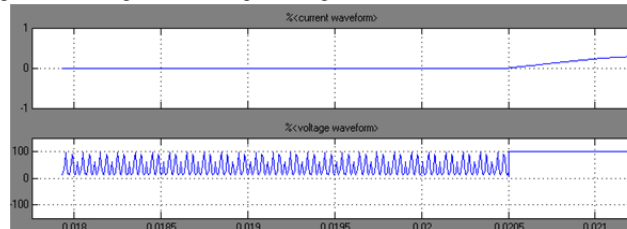


Figure 17: More enlarge view of output voltage and current waveform of fig.16

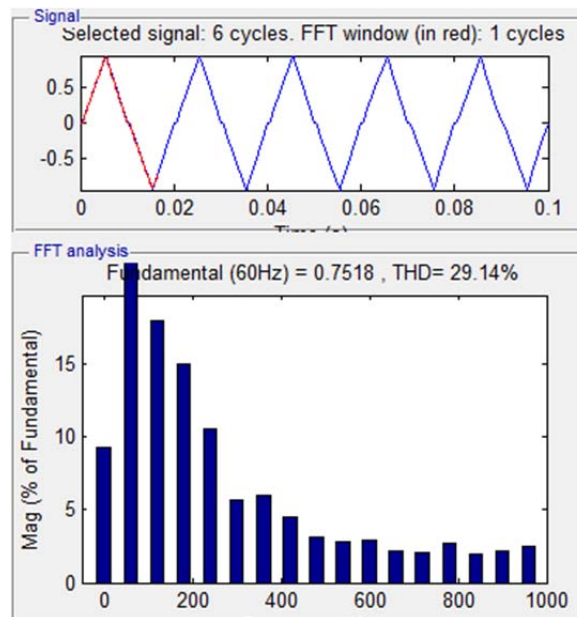


Figure 18: Fast Fourier Transform curve of above figure 15

CONCLUSION

The main objective of this paper is to obtain nonlinear behaviour of converter at different loading condition which converts dc voltage into ac voltage with the help of power semiconductor device effectively. Nonlinear phenomena are investigated in single phase H bridge inverter. The model of the single phase DC to AC converter is analyzed. Based on the simulated model of the inverter and the simulation results shows the peculiar behavior when the load of the single phase inverters is changed because load is taken as bifurcation parameter. Voltage and current waveform are obtained, which shows that inverters operates in period one, period two and enters to chaotic mode as the bifurcation parameter (load) changes. This information is very useful for designing practical hardware circuits before fabrication reality.

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