iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 6 **Issue:** III **Month of publication:** March 2018

DOI: http://doi.org/10.22214/ijraset.2018.3696

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue III, March 2018- Available at www.ijraset.com

Study of Nonlinear and Complex Behavior of Inverters and Multistepped Power Inverter

Sanjeev Kumar[1], G.K Banerjee[2], Piush Kumar Garg[3]
[1] Asst. Prof., Dept. of EN, SRMSCET, Bareilly, Uttar Pradesh, India.
[2] Professor, Dept. Electrical Engineering, IFTM University, Moradabad, Uttar Pradesh, India
[3] Associate. Prof., Dept. of EN, SRMSCET, Bareilly, Uttar Pradesh, India

Abstract: A study has been done for investigating nonlinear complex behavior bifurcation and chaos phenomena in various kind of single phase and three phase dc to ac inverter along with multi stepped wave inverter. The converters are simulated using a software package MATLAB/SIMULINK. It is investigated that many different types of power inverters tends to move from periodic operating state to chaotic operation state as the bifurcation parameter like input voltage frequency and nature of load to the inverter is varied. There are many sources of unwanted nonlinearity in practical power inverters. In addition, their operation is characterized by switching that generates a variety of nonlinear dynamics Simulated results output voltage and current waveform of single and three phase inverter along with multi stepped wave inverter (eleven stepped) are validated by waveforms and FFT spectrum.

The inverters with more number of steps can generate good quality voltage waveforms. In order to analyze the circuit behavior we obtained voltage and current waveforms obtained from the circuit simulation have been studied and also the FFT (Fast Fourier Transform) spectrums for the outputs are compared along with various responses of inverters at different loading conditions. This information playing a major role for designing practical circuits in power electronics.

Keywords: Nonlinearities, Chaos, Bifurcation, Multi Stepped inverter, Cascaded H-bridge

I. INTRODUCTION

All varieties of power electronics dc to ac converters may be classified as nonlinear time-varying dynamical systems because they exhibit a wealth of nonlinear phenomena, including various kinds of bifurcations and chaos. The Principal source of non-linearity is the inherent switching action and presence of nonlinear components (e.g. the power diodes) and control methods (e.g. pulse-width modulation). These nonlinearities are a potential source of engineering malfunction and failure. In order to skip these phenomena it is very important to identify and analyze these nonlinear phenomena of a converter.

The occurrence of bifurcations and chaos phenomena in power electronics systems was initially observed in the literature by Hamill [1] in 1988. Experimental results verification related to bounded ness, chattering and chaos were also made by Krein and Bass [2] back in 1990. Although these primary observation did not contain any rigorous analysis, they provided solid evidence of the importance of studying the complex behavior of power electronics and its possible benefits for practical design. Using an implicit iterative map, the generation of period-doublings, sub-harmonics and chaos in a simple buck converter was demonstrated by Hamill [3] using numerical analysis, PSPICE simulation and laboratory measurements. The systematic approach for the derivation of a closed-form iterative map of the boost converter under a current-mode control mode scheme was explained later by the similar group of researchers [4,5].Further work on the bifurcation behavior of the buck converter was observed by Chakrabarty [6] who specifically studied the bifurcation behavior by the variation of a range of circuit parameters including storage inductance, load resistance, output capacitance, etc. In 1996, Olivar and Fossas [7] submitted a detailed analytical explanation of the step down (buck) converter dynamics, identifying the topology of its chaotic attractor and studying the regions associated with different system evolutions.

Power electronics is a relatively new and fast-developing area of electronics with wide real practical application. In particular, the stability and the nonlinearity, bifurcation analysis of the power electronics systems with the pulse-width modulation (PWM) technique has attracted much interest in recent years [8], [9]. Over the past years, one new variety of bifurcation phenomena called border-collision bifurcation has been observed for one or two-dimensional one-parameter families in discrete systems [10], [11].In this paper main emphasis of author for study and analyze nonlinear and complex typical behavior of different inverter and multistepped inverter in more advanced manner [15].

In reality, nonlinear behavior and bifurcation is generally to be avoided in every types of power electronics systems, but it is also valid that designing a dynamical system too remote from bifurcation boundaries may degrade performance characteristics. Hence, efforts have been applied to study and analyze the nonlinear behavior of systems, bifurcation and chaos in single, three and multi stepped inverters, to show the practical relevance of nonlinearities, bifurcations and chaos in power electronics systems. Under the first stage simulation are carried out for the single and three phase H-bridge inverters, to investigate nonlinearities. In order to provide reliable and stable operation for conversion dc in to ac, input dc supply can be obtained from battery, fuel cell,Chopper,solar cell etc. In second stage, the eleven stepped inverter (multi stepped) is achieved by cascading five single phase H-bridge inverter. This stepped wave inverter has fixed dc input voltage and a variable output ac voltage as number of H-bridge inverter increases or decreases. These inverters are simulated through a powerful software package MATLAB/SIMULINK. Different voltage, current waveforms at output terminals of inverter system and FFT spectrum are obtained by varying in bifurcation parameter values to obtain nonlinearities and complex behavior. Input voltage, frequency and nature of output load (R, R-L etc.) can be taken as bifurcation parameters. This paper presents, we are dealing with many dc to ac power converters, which by virtue of their huge amount of nonlinearity exhibit a variety of complex behavior and chaos.

II. BASIC PRINCIPLE

A single phase three stage H-bridge inverter is shown in Fig. 1. This single phase inverter provides the three state output as well as converts pure dc in to ac .It consist of four Power semiconductor devices which operates as switches(T_1,T_2,T_3,T_4), to the output voltage of desired magnitude and frequency. At the same time only two switches operates and remaining two switches are in off stage. In below table1 one stand for turn on state of switch and zero stand for turn off state of switch.

TABLE 1: Switching States Single Phase Inverter

T_1	T_2	T_3	T_4	V_A	V_B
1	0	1	0	$+\frac{Vs}{2}$	$-\frac{Vs}{2}$
0	1	0	1	$-\frac{Vs}{2}$	$+\frac{Vs}{2}$
1	0	1	0	$+\frac{Vs}{2}$	$-\frac{Vs}{2}$
0	1	0	1	$-\frac{Vs}{2}$	$+\frac{Vs}{2}$

This circuit is easily realized by four power semiconductor switches, a dc supply voltage source, an inductor and a resistor. The four switches are named by T_1, T_2, T_3, and T_4. This circuit has the following two conditions.

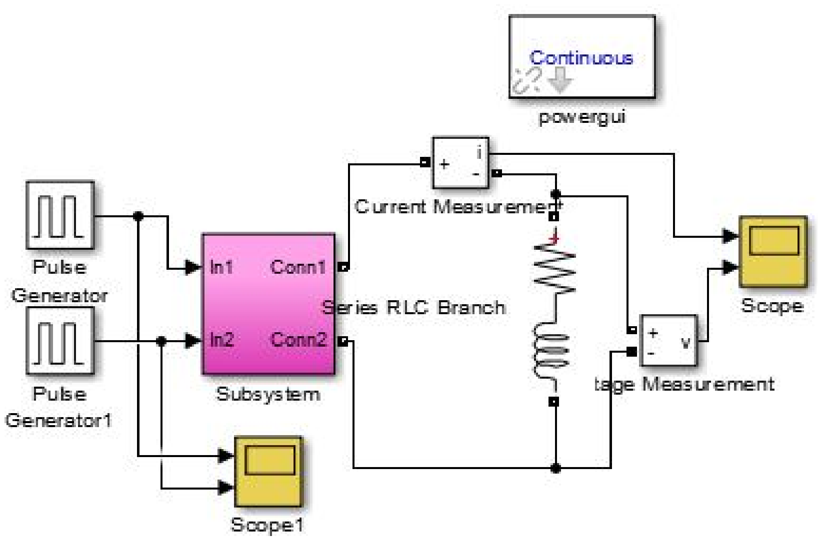


Fig. 1: Simulink model of Single phase H-Bridge inverter

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue III, March 2018- Available at www.ijraset.com

Table 2: Switching States of switches in single Phase Inverter

State A: T1 and T3: ON T2 and T4: OFF,	State B: T1 and T3: OFF T2 and T4: ON,

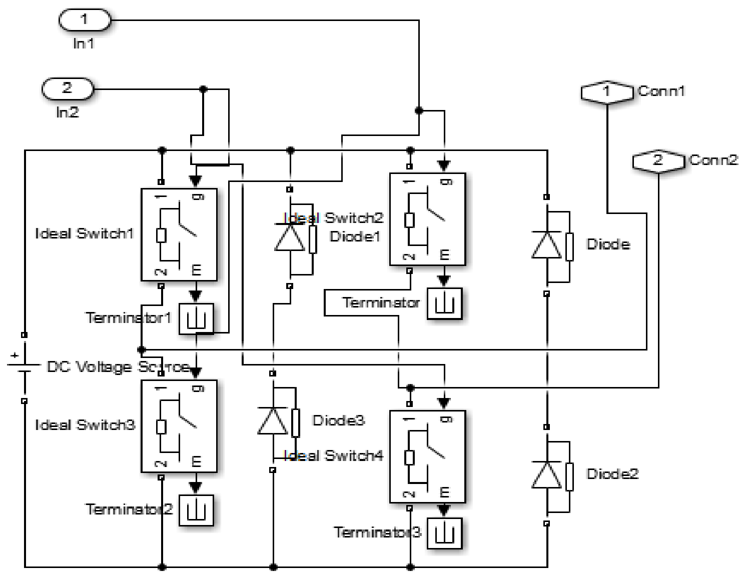


Fig. 2: Represents internal circuit for subsystem of inverter

H Bridge DC-AC converter operating waveforms is shown in Fig. 5. In one switching cycle, the arriving of clock pulse drives T1 and T3 on, T2 and T4 off, the inductor current increases; when the inductor current reaches the compensated current reference *i*ref, T1 and T3 off, T2, T_4 on, the inductor current begins to decline. While in three phase inverter number of Switches are six (T_1,T_2,T_3,T_4,T_5,T_6).All these semiconductor switches are conducting current through them only when they are triggered by gate pulses. To obtain gate pulses on gate terminal for conduction of inverter system for single and three phase inverter system firing angles determined through pulse width modulation technique for triggering switches. The basic circuit

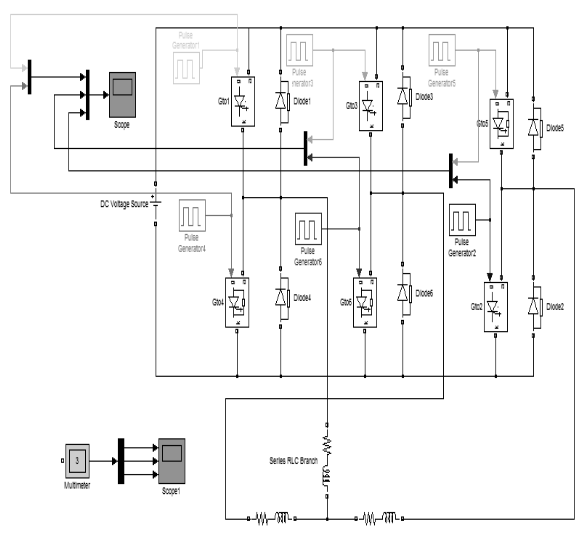


Fig. 3: Represent Matlab / Simulink model of three phase H-Bridge inverter of three phase full bridge

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue III, March 2018- Available at www.ijraset.com

Inverter is shown in the following figure 2. This inverter circuit consist of six power semiconductor switches associated along with freewheeling diodes. The switching of switches are periodically in the well proper sequence to produce the desired output waveforms. The states of switching determines frequency of the inverter.

TABLE 3: SWITCHING STATES THREE PHASE INVERTER

S.No.	Switching Interval	Turn-on devices	Conducting Sequence of devices
1	0^o-60^o	T_1	T_5 T_6 T_1
2	60^o-120^o	T_2	T_6 T_1 T_2
3	120^o-180^o	T_3	T_1 T_2 T_3
4	180^o-240^o	T_4	T_2 T_3 T_4
5	240^o-300^o	T_5	T_3 T_4 T_5
6	300^o-360^o	T_6	T_4 T_5 T_6

Switch pair in each leg, i.e. T_1, T_2, T_3, T_4, T_5, T_6 are turned-on with a time interval of 180^o. It means that switches T_1 conduct for 180^o and switch T_4 for the next 180^o of a cycle. Switches, in the upper group, i.e. T_1 T_3, T_5 conduct at an interval of 120^o. It means that if T_1 is fired at 0^o, than T_3 must be triggered at 120^o and T_5 at 240^o.Same is true for lower group of switches.

The following points can be noted from the waveform and operating table.

1) Each switch conducts for a period of 180^o.
2) Switches are triggered in the sequence 1, 2,3,4,5 and 6.
3) Phase shift between triggering the two adjacent switches is 60^o.From the table, it is observed that in every step of 60^o duration, only three switches are conducting.
4) The output voltage waveform are quasi square wave with a peak value of Vs.
5) The three phase voltages V_{AN}, V_{BN} and V_{CN} are six step waves with step heights of $V_S/3$ and (2/3) Vs.
6) Line voltage V_{AB} is leading the phase voltage V_{AN} by 30^o.

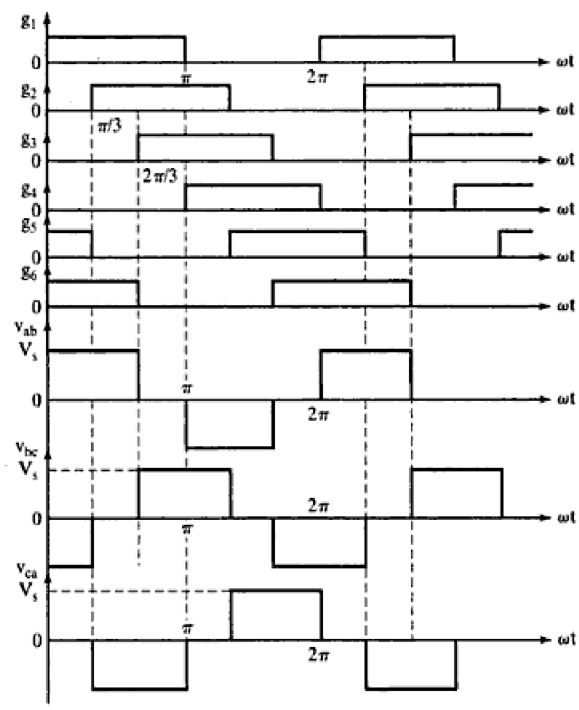


Fig. 4: Represents output voltage waveform for 180^0 mode of three phase H-Bridge inverter

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue III, March 2018- Available at www.ijraset.com

In second stage, an eleven stepped inverter system designed to get desired ac from input dc supply. Five single phase H-bride inverters cascaded to achieve that eleven stepped wave inverter. Cascaded stepped wave H- bridge inverters have been proposed for that type of applications as static var generation, an interface with renewable energy sources, and for battery-based applications. Cascaded multi stepped inverters are ideal for connecting renewable energy sources with an ac grid, because of the need for separate dc sources, which is the case in applications such as photovoltaics or fuel cell.

Table 4: Switching States Parameters For Three Phase Inverter At 50 % Period Of Pulse Width

Pulse generator	Delay in degree	Amplitude	Periods (sec)	Phase delay (sec)
1	0^0	3	0.6	0
2	60^0	2	0.6	0.1
3	120^0	2.5	0.6	0.2
4	180^0	3	0.6	0.3
5	240^0	2	0.6	0.4
6	300^0	2.5	0.6	0.5

From the single phase structure of a cascaded H-bridge inverter as shown in Fig. 1 above, we can make the three stepped, Five stepped, seven stepped nine stepped and eleven stepped

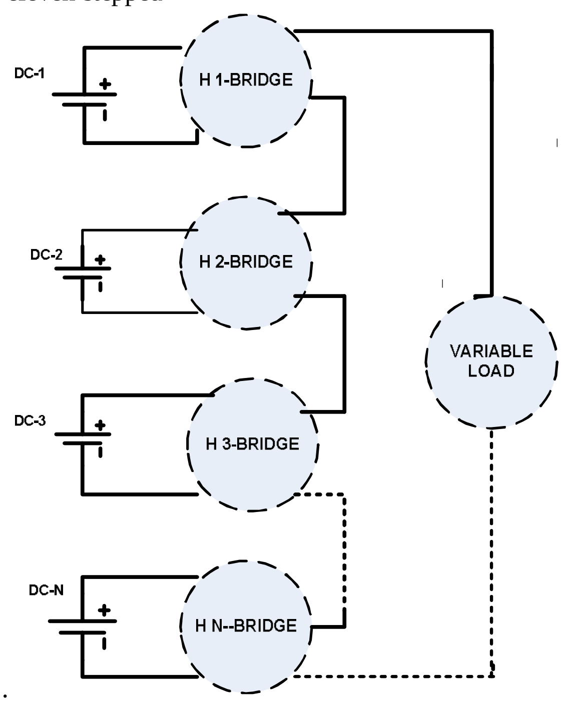


Fig. 5: Block diagram of multi stepped inverter

Inverters without using any type of modulation technique, and by this topology, the number of output-phase voltage steps is defined. By X= 2Y+1, where 'X' is the no of steps and 'Y' is the number of DC energy sources. So, for an example the output phase voltage of eleven stepped wave inverter is given by

$Van= Va_1+Va_2+Va_3+Va_4+ Va_5$ (1)

Where Va_1,Va_2,Va_3,Va_4,Va_5 are the voltages across output terminals of h-bridge inverters of multi stepped inverter.

$Van= Va_1+Va_2+Va_3+Va_4$ (2)

This output voltage shown in equation (2) is valid for seven stepped inverter which require three h-bridge inverter.Simelarly output voltage of different stepped inverter can be obtain.

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

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue III, March 2018- Available at www.ijraset.com

the following map:

$I_{n+1} = I_n + m_1T$ if $I_n \le I_{ref} - m_1T$ (3)

$I_{n+1} = I_{ref} - m_2t_n$ if $I_n > I_{ref} - m_1T$ (4)

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 a low ripple output voltage of constant average value $V_{out,}$ the constants $m_{1,}$ m_2 and □ can be expressed as:

Table 5: slopes magnitudes and ratio of slopes magnitude

Slope	Value
m_1	$(V_{in} - V_{out}) / L$
m_2	V_{out}/L
□	$(m_2/m_1) = V_{out} / (V_{in} - V_{out})$

Here □ is the ratio of slopes magnitude. If □>1 then, state of operation of the inverter is unstable and circuit has no stable periodic solution. Fig. 2 shows a typical segment of the inductor current, $I_{L,}$ of a dc-ac converter under current mode control in the chaotic regime.

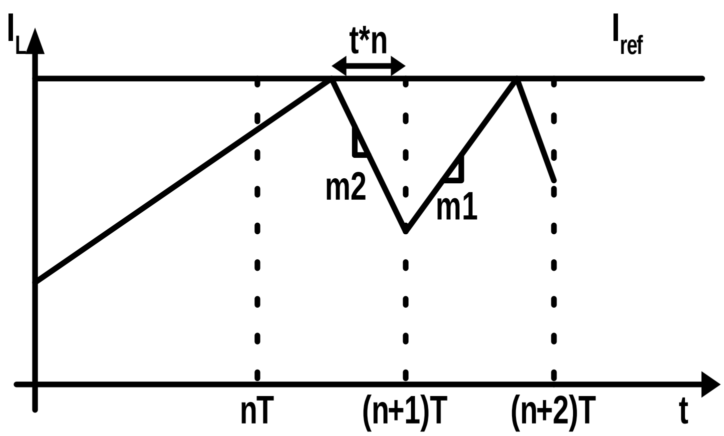


Fig. 6: Typical segment of inductor current for chaotic regime,□□>1

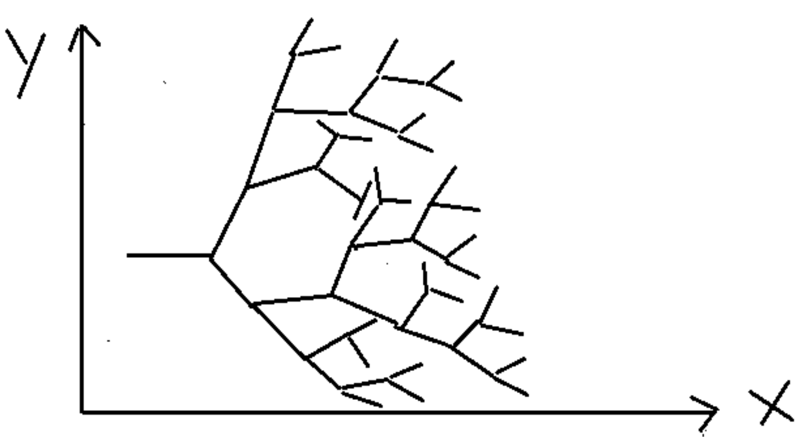


Fig. 7(a): Bifurcation diagram

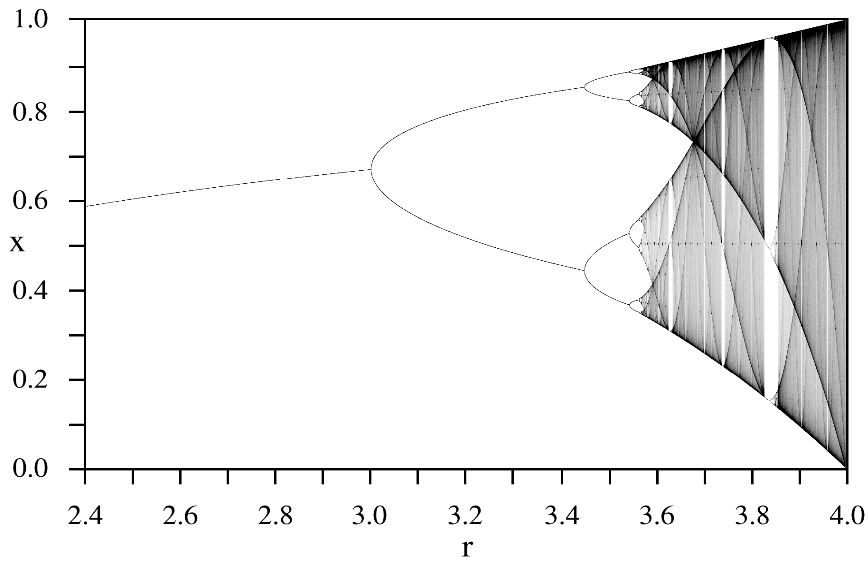


Fig. 7(b): Bifurcation diagram when bifurcation parameter r Varies between 0-4

A bifurcation is a period-doubling, a change from an N-point attractor to a 2N-point attractor, which occurs when the control parameter is changed. It is a visual record of the succession of period-doubling generated as bifurcation parameter r increases.

III. SELECTION OF PHASE ANGLE DELAYS FOR DESIGNING THREE STEPPED, MULTI STEPPED SINGLE PHASE H-BRIDGE INVERTERS:

Phase delay values for turn on semiconductor switches at desired instant of power inverters can be obtained as follow

PHASE DELAY = $\frac{FIRING ANGLE}{360^0}$ **TIME PEROD*

For 50Hz frequency. T = $\frac{1}{f}$ = 1/50 = 0.02

Phase angle delays are to be measured at different firing angles to obtain desired switching pattern to turn on inverter switches through these above relations

Table 6: Phase Angle Delay Values For Single Phase H Bridge Inverters

Frequency	f = 50Hz
Time period	T = 20ms
Phase angle delay for switch T_1	Θ_1=0.0005ms
Phase angle delay for switch T_2	Θ_2=0.0105ms
Phase angle delay for switch T_3	Θ_1=0.0005ms
Phase angle delay for switch T_4	Θ_2=0.0105ms

Table 7: Phase Angle Delay Values For Multi Stepped Single Phase H Bridge Inverters

Frequency	f = 50Hz
Time period	T = 20ms
Phase angle delay for H_1	Θ_1= 0.0005ms Θ_2= 0.0105ms Θ_3= 0.0105ms Θ_4= 0.0105ms
Phase angle delay for H_2	Θ_5= 0.0010ms Θ_6= 0.0110ms Θ_7= 0.0010ms Θ_8= 0.0110ms
Phase angle delay for H_3	Θ_9 = 0.0015ms Θ_{10}= 0.0115ms Θ_{11}= 0.0015ms $\Theta 1_2$= 0.0115ms
Phase angle delay for H_4	Θ_{13}= 0.0020ms Θ_{14}= 0.0120ms Θ_{15}= 0.0020ms Θ_{16}= 0.0120ms
Phase angle delay for H_5	Θ_{17}= 0.0025ms Θ_{18}= 0.0125ms Θ_{19}= 0.0025ms Θ_{20}= 0.0125ms

IV. SIMULATION RESULTS

All inverter circuits shown in Fig.1,Fig.3 and Fig.21 are simulated with the powerful software package MATLAB/SIMULINK Fig. 8 represents the Output voltage waveform of single phase h-bridge inverter (period one operation) with input voltage 3V and R=10Ω, frequency=50Hz . Switching pulses of switches for single phase inverter shown in fig.8 (a). FFT spectrum of single phase inverter for voltage shows THD 40.96% in fig.9. Figure 10 shows Output voltage and current waveforms of single phase inverter voltage when V_{in} = 3V, R=10Ω, L=0.10mH parameter value. Fig.10 (a), fig.10 (b) provide information of THD (36.72%) for both voltage and current. Figure 14 shows output voltage waveform of single phase inverter when values of inverter parameter are V_{in} = 3V, R=10Ω, L=10mH and Figure.13 (a), 13(b) presents THD=36.71% for voltage and THD=55.21% for current in FFT spectrum of single phase inverter for voltage and current respectively at V_{in} = 3V, R=10Ω, L=10mH values. These results taken on single phase inverter when load is considered as bifurcation parameter.

Figure.11 shows enlarge view of output voltage and current waveform when V_{in}=300V, R=10□, L=10mh, frequency=50Hz which gives stable period-1 operation and first orbit comes into existence. Hence the converter operates in period one operation. Unstable states of voltage and current waveforms when input voltage=300V, R=100 Ω, L=60mh, frequency=50Hz indicated in Fig. 12 and also Fig. 13 shows unstable states as voltage varied as bifurcation parameter from 300V to 200V.Therefore this orbit subsequently undergoes a border-collision, and around that point another coexisting higher period orbit comes into existence. First one waveform shows the output current waveform, which reaches in to chaotic state value. Hence the inverter moves to operates in period one operation to chaotic mode operation as bifurcation parameter changes.

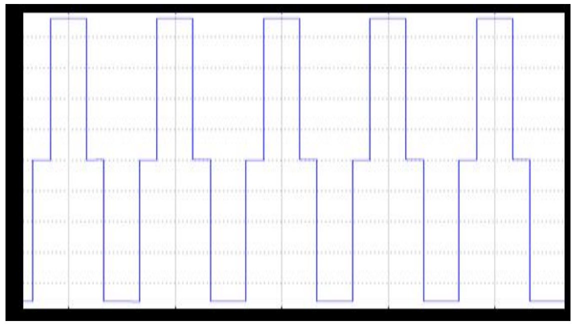


Fig. 8: Output voltage waveform of single phase inverter (at V_{in} = 3V, R=10Ω, period one operation)

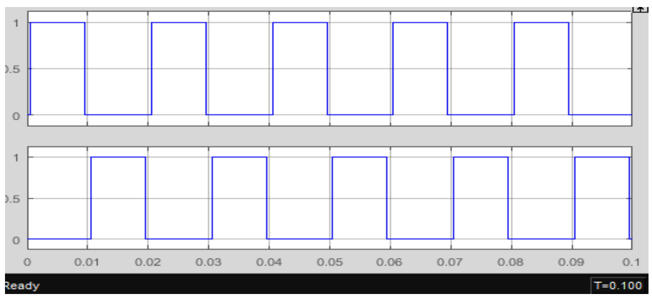


Fig.8 (a): Represents switching pulses for switches single phase inverter

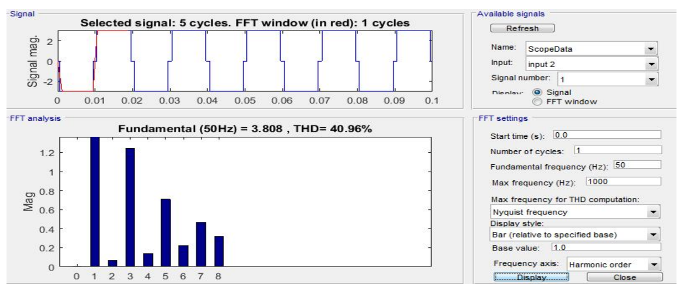


Fig. 9: FFT spectrum of single phase inverter for voltage (V_{in} = 3V, R=10Ω, THD=40.96%)

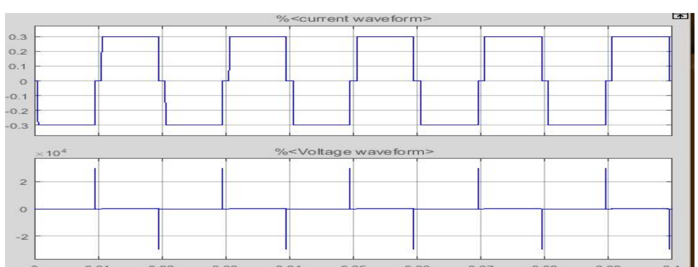


Fig. 10: Output voltage and current waveforms of single phase inverter voltage (at V_{in} = 3V, R=10Ω, L=0.10mH)

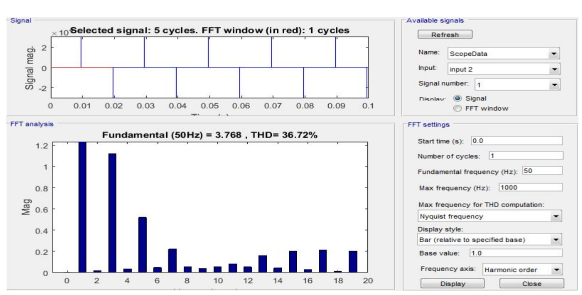


Fig.10 (a): FFT spectrum of single phase inverter for voltage (V_{in} = 3V, R=10Ω, L=0.10mH, THD=36.72%)

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue III, March 2018- Available at www.ijraset.com

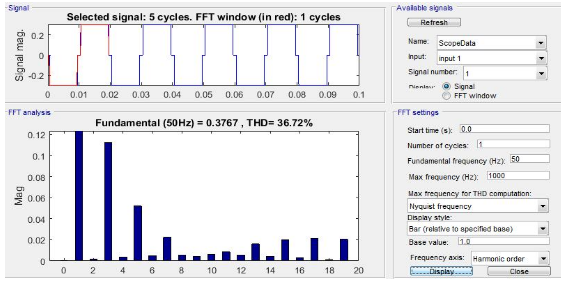


Fig.10 (b): FFT spectrum of single phase inverter for current (V_{in} = 3V, R=10Ω, L=0.10mH, THD=36.72%)

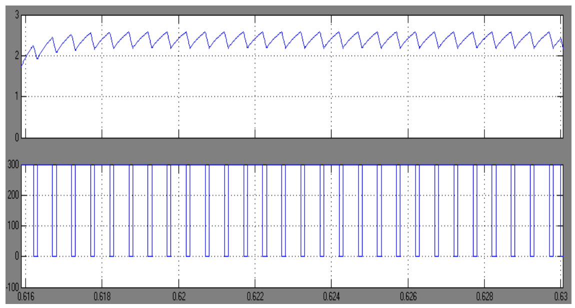


Fig.11: Enlarge view of output voltage and current waveform at V_{in}=300V, R=10Ω,

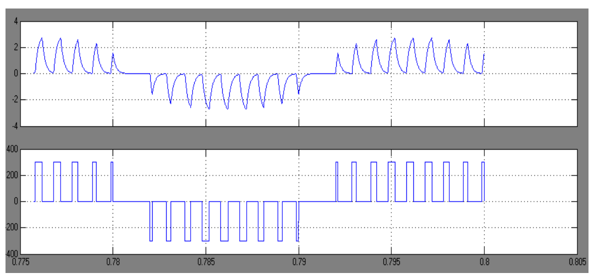


Fig.12: Enlarge view output voltage and current waveform V_{in}=300V, R=10Ω

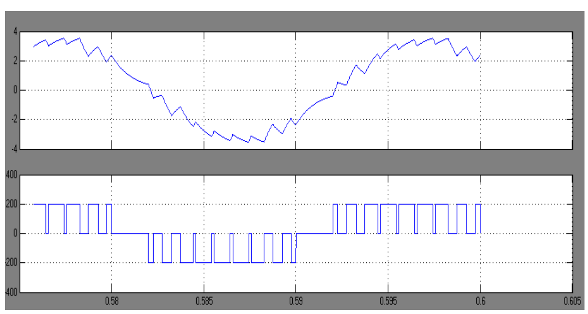


Fig.13: Enlarge view of output voltage and current waveform in unstable state at V_{in}=200V

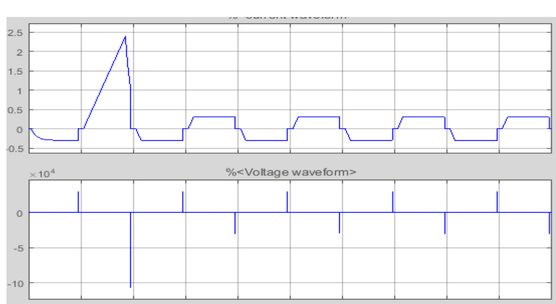


Fig.14: Output voltage waveform of single phase inverter (at V_{in} = 3V, R=10Ω, L=10mH)

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue III, March 2018- Available at www.ijraset.com

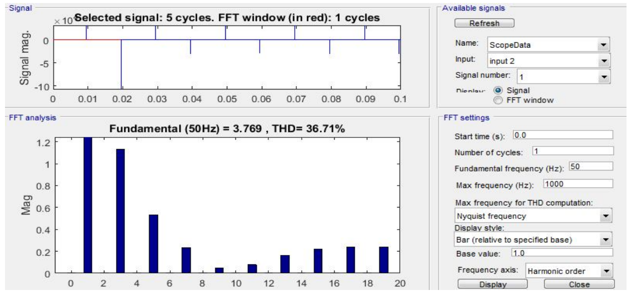


Fig.14 (a): FFT spectrum of single phase inverter for voltage (V_{in} = 3V, R=10Ω, L=10mH, THD=36.71%)

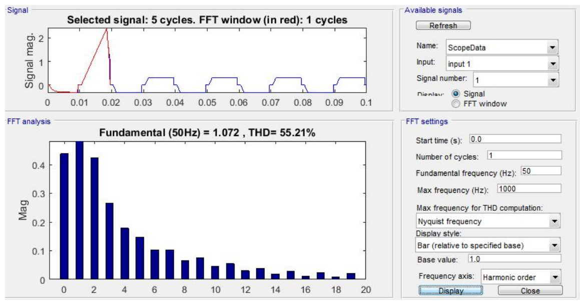


Fig.14 (b): FFT spectrum of single phase inverter for current (V_{in} = 3V, R=10Ω, L=10mH, THD=55.21%)

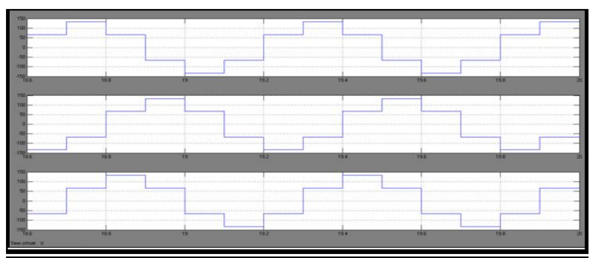


Fig. 15: Output Voltage Waveform of Three Phase Power Bridge Inverter

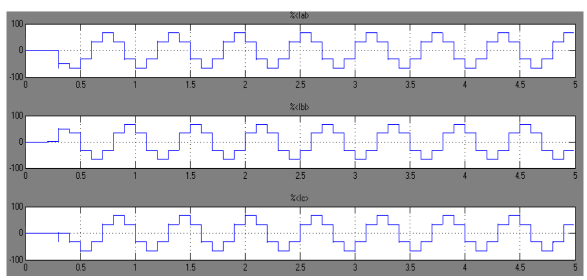


Fig.15 (a): Phase voltage waveform of three phase inverter

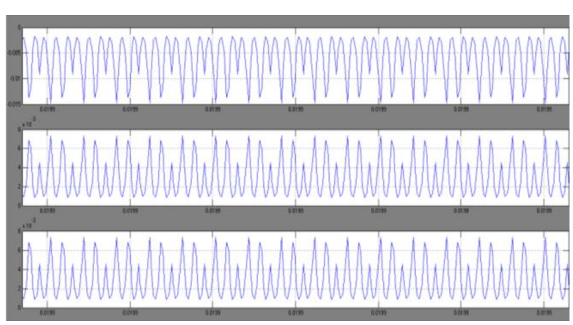


Fig. 16: Distorted load current after variation in Load

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue III, March 2018- Available at www.ijraset.com

Fig. 15, shows output phase voltage waveforms of three phase power bridge inverter through scope at end terminals of inverter .In figure 15(a) phase voltages are shown in more clear form using millimeter as measurement tool when input voltage, V_{in}=100volt, R=100 Ω,, L=15mh, modulation index=035 frequency being 200Hz. the inverter operates in period one operation at this stage.Fig.17 and Fig.18 gives voltage waveform of Three phase Power H-Bridge inverter in unstable mode on input supply Vin = 200V, R=100Ω, L=10mh, modulation index = 0.75, carrier frequency= 200Hz as the bifurcation parameter is varied. Fig. 16 shows the Distorted load current waveform of Three Phase Inverter after variation in Load

The same bifurcation structure is obtained when the bifurcation parameter are changed to original value. Fig. 18 Enlarge view of output voltage waveform in chaotic mode that shows inverter enter stable operation to unstable operating state.

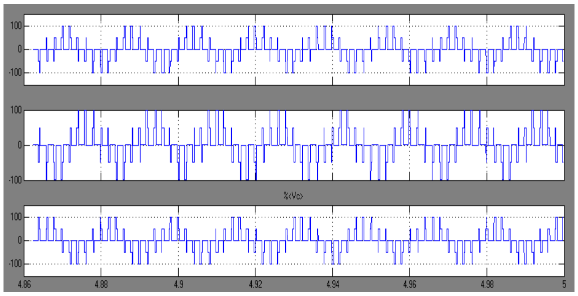


Fig. 17: Distorted voltage waveform of Three Phase Power H-Bridge Inverter

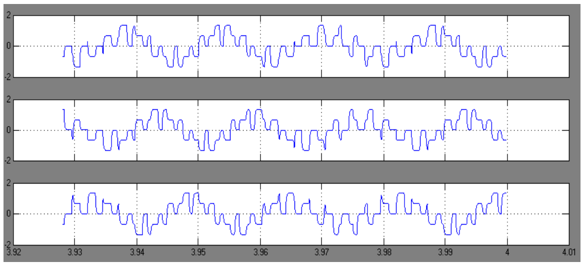


Fig. 18: Enlarge view of voltage waveform of three phase power H-Bridge Inverter in unstable mode

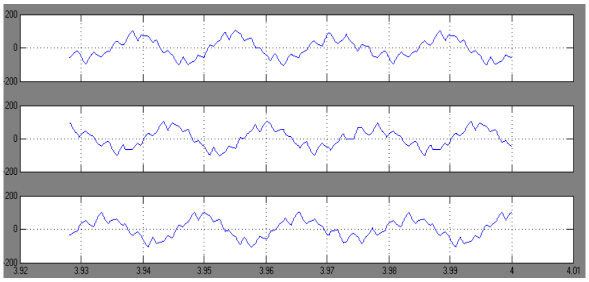


Fig. 19: Voltage waveform of Three Phase Power H-Bridge Inverter ln chaotic mode

Fig. 20 shows an enlarged view of the output voltage waveform when input voltage is 45V. Voltage waveform shows irregular pattern as the value of bifurcation parameter (load, input voltage) changed. It is bounded by maximum reference value and missed some clock pulses. Inductor current states do not repeat at the clock instant. Hence converter operates in chaotic mode

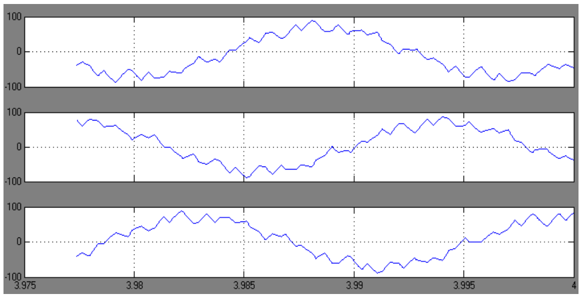


Fig.20: Enlarge view of Voltage waveform in chaotic mode

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue III, March 2018- Available at www.ijraset.com

V. SERIES CASCADED MULTI STEPPED H-BRIDGE POWER INVERTER

The new development in the area of power electronics and microelectronics made it possible to reduce the magnitude of harmonics with multi stepped inverters, in which the number of steps of the inverters are increased rather than increasing the size of the filters. The performance of multi stepped inverters enhances as the number of steps of the inverter increases.

The AC outputs of various full h-bridge inverters are connected in series such that the synthesized voltage waveform is the sum of the individual converter outputs.

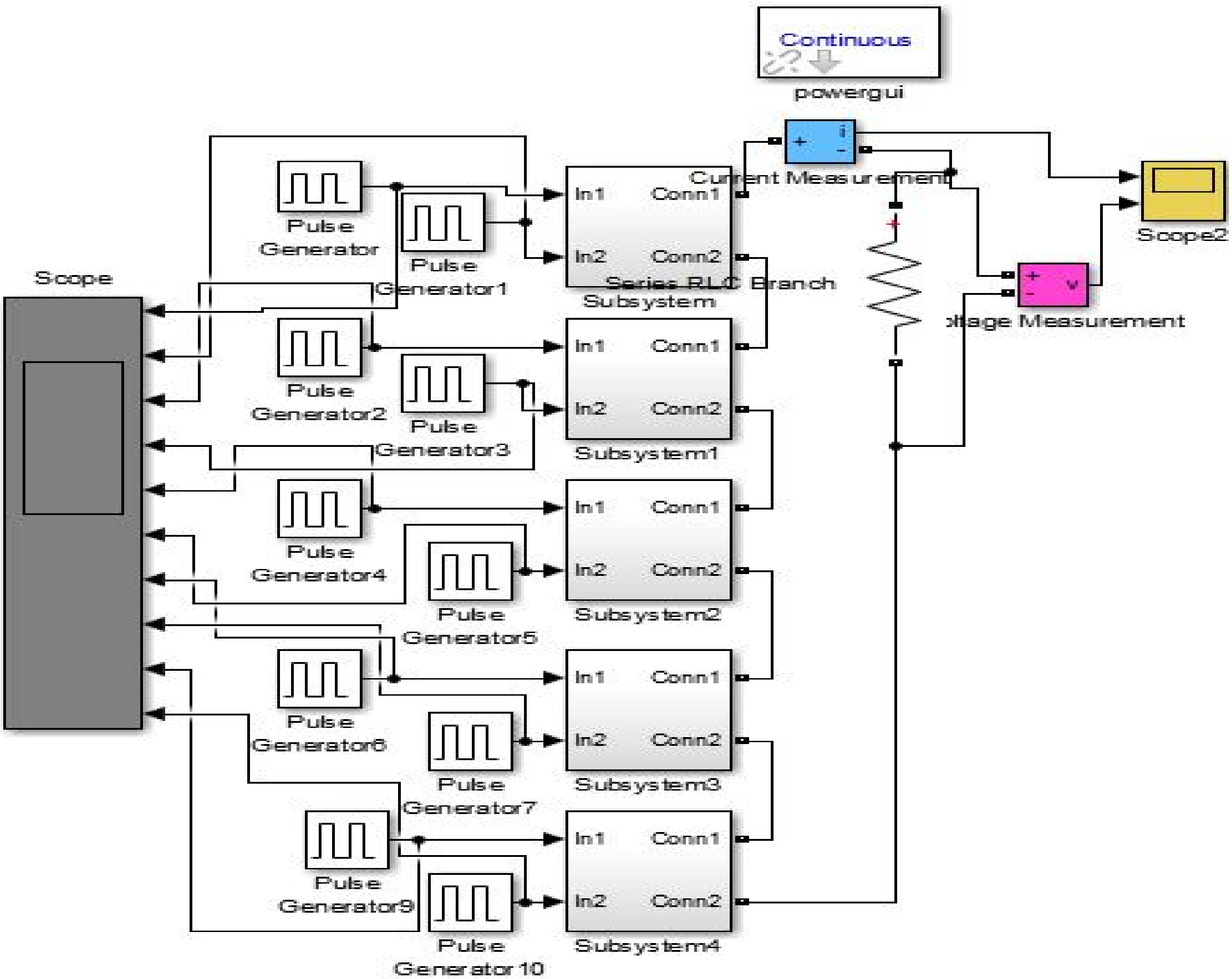


Fig. 21: Represents simulink model of multi stepped (Eleven Stepped) wave inverter

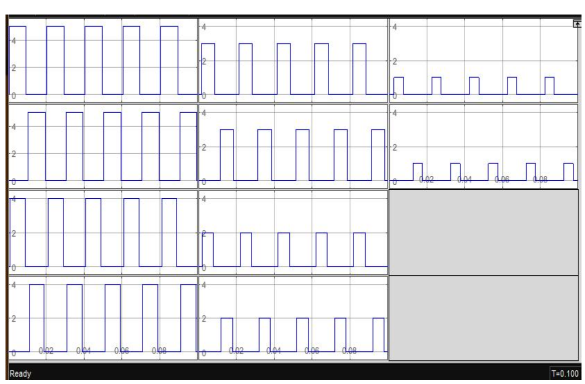


Fig. 21(a): Individual gate pulses for switching multi stepped wave inverter switches

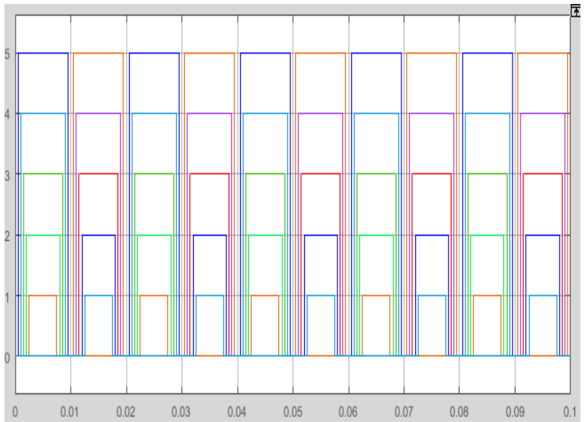


Fig.21 (b): Gate pulses of bridge inverter on one axes for multi stepped wave inverter switches

VI. SIMULATION RESULTS AND ANALYSIS OF MULTI STEPPED INVERTER

Simulation results are obtained by observing voltage and current waveforms at variable load and input supply voltage (V_{in}) as bifurcation parameter. Figure 21 represents Simulink model of eleven stepped inverter which is multi stepped inverter. For operating this multi stepped inverter separate gate pulses applied to power semiconductor switches. Individual gate trigger pulses for switching multi stepped wave inverter switches shown in figure 21(a) these gate pulses of bridge inverter presents on one axes for multi stepped inverter are shown in figure 21(b) for easy understanding operation of this eleven stepped inverter. When the input supply voltage V_{in} varies from higher voltage to lower voltage, there is change in the dynamics. Figure 22 demonstrates the output voltage and current waveform when supply voltage value Vin = 3V and load have only R=10 Ω. This waveform is periodic (period-1 operation). Figure 23 illustrate FFT spectrum of eleven stepped inverter for voltage at Vin = 3V, R=10Ω and THD=38.16 % recorded in this situation. In Fig.20 shows the output voltage and current waveform in unstable state when R=10 Ω, L=10mH and input supply voltage Vin =3V. Figure 24 and fig.27 shows output voltage and current waveform in unstable state of eleven stepped for the corresponding chaotic or strange attractor (graph between output voltage and current) has been drawn. Inverter has transitioned by means of period doubling from periodic to chaotic operation. In short, power electronic circuits can exhibit nonlinear dynamics for example bifurcations, sub harmonic oscillations and chaos as the bifurcation parameter varied from one to next value.Fig.25 & fig.26 shows FFT spectrum of multi stepped (11 Stepped) inverter for o/p voltage & current when V_{in} = 3V, R=10Ω, L=0.1mH ,THD=48.26 and 48.31% for voltage and current output respectively. Similarly output voltage and current waveform shown in fig.27 supports to figure 28 and fig.29 when L changes from 0.10mH to L=10mH and corresponding THD are 36.71% for voltage and 53.37% for current.

It is observed that the inductor current waveform during the switch on and switch off of the switch has “ringing” (fast damped oscillations) due to the presence of parasitic. From fig.30 to fig.34 it has been observed that when bifurcation parameters varies inverter moves toward nonlinearity, chaos and follow complex behavior through following the path of period one, period two and finally reaches to chaos indicated by output voltage and current waveforms .

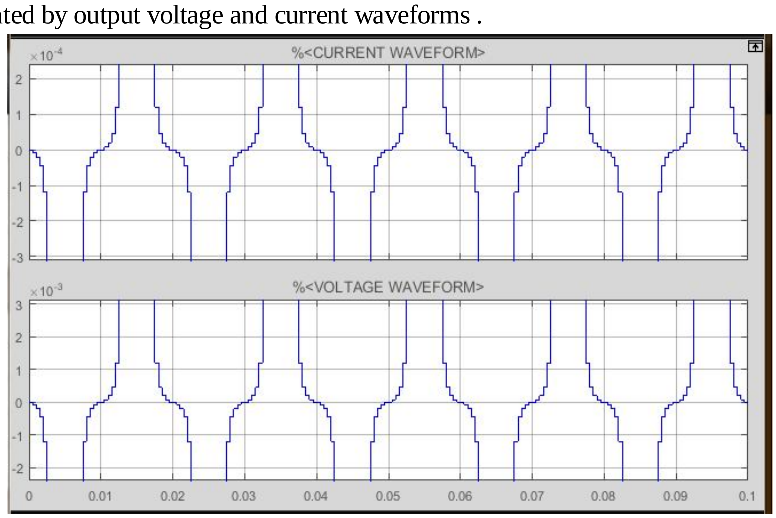


Fig 22: Enlarge view of output voltage and current waveform in stable state on R=10 ohm (period-1)

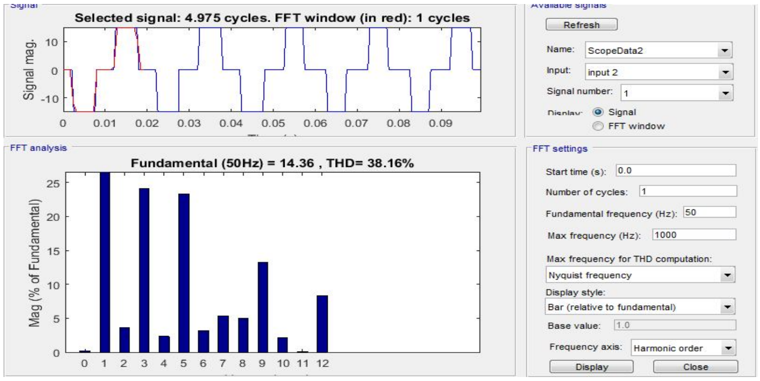


Fig. 23: FFT spectrum of eleven stepped inverter for voltage (Vin = 3V, R=10Ω, THD=38.16 %)

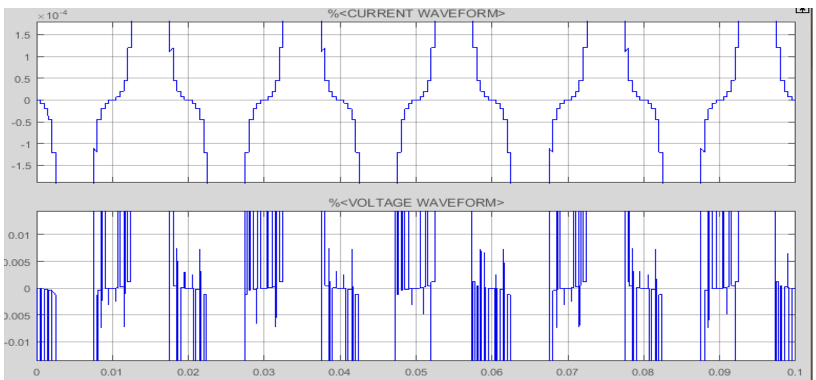


Fig. 24: Distorted output voltage and current waveform in unstable state (Vin = 3V, R=10Ω, L=0.1mH)

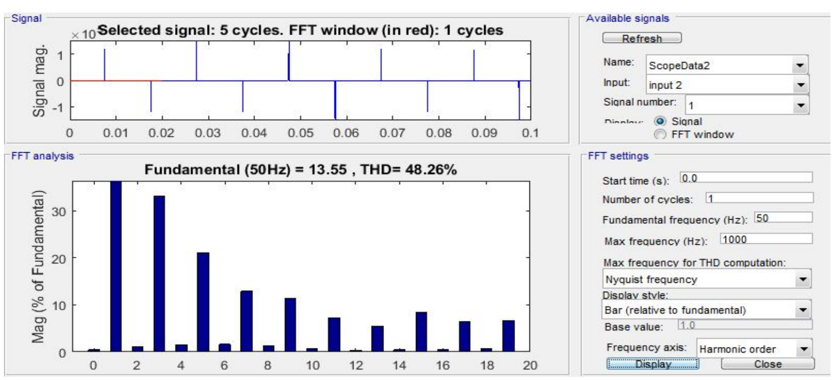


Fig. 25: FFT spectrum of multi stepped inverter for o/p voltage (V_{in} = 3V, R=10Ω, L=0.1mH, THD=48.26%)

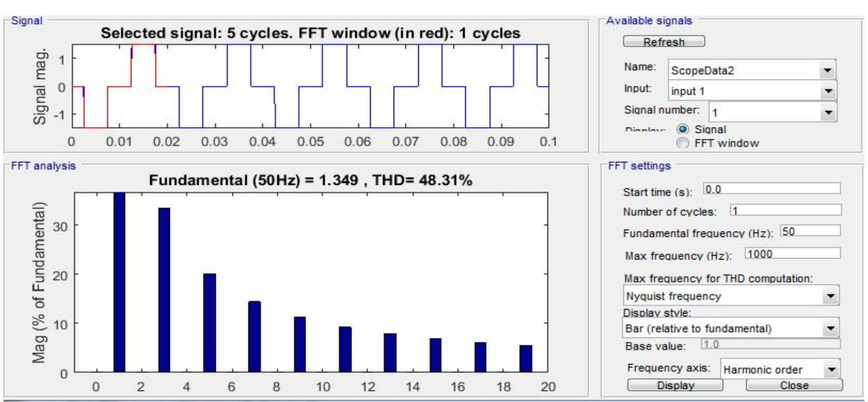


Fig 26: FFT spectrum of multi stepped inverter for o/p current (V_{in} = 3V, R=10Ω, L=0.1mH) THD=48.31%

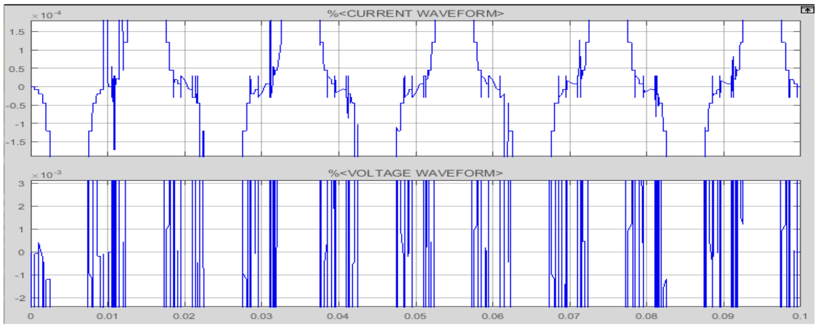


Fig. 27: Distorted output voltage and current waveform in unstable state L=10mH

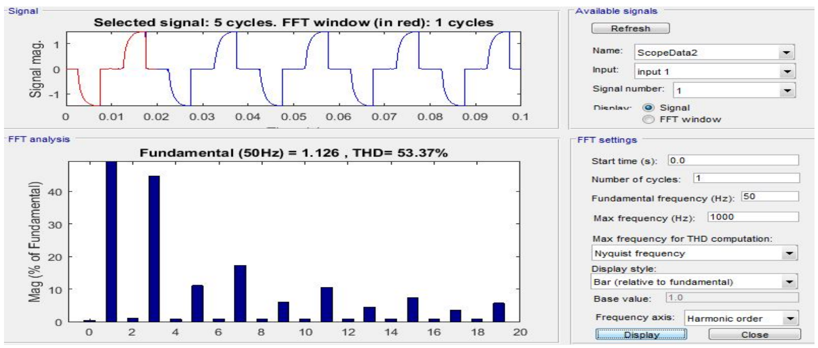


Fig. 28: FFT spectrum for current of multi stepped inverter for o/p voltage (V_{in} = 3V, R=10Ω, L=10mH)

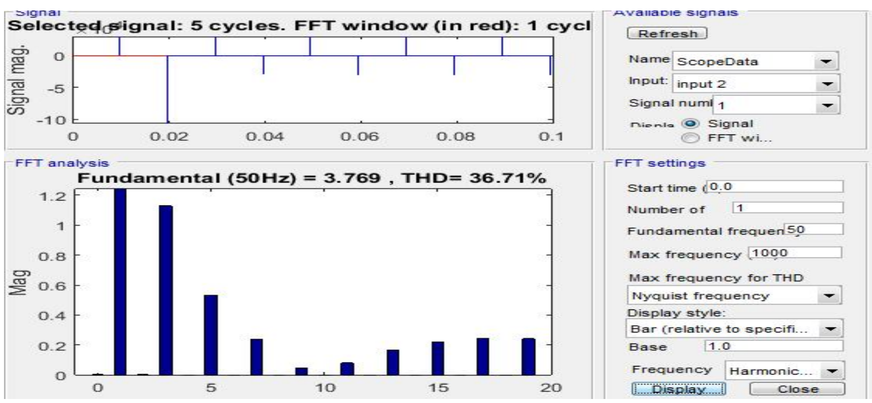


Fig. 29: FFT spectrum of three stepped inverter for voltage (V_{in} = 3V, R=10Ω, L=10mh, THD=36.71 %)

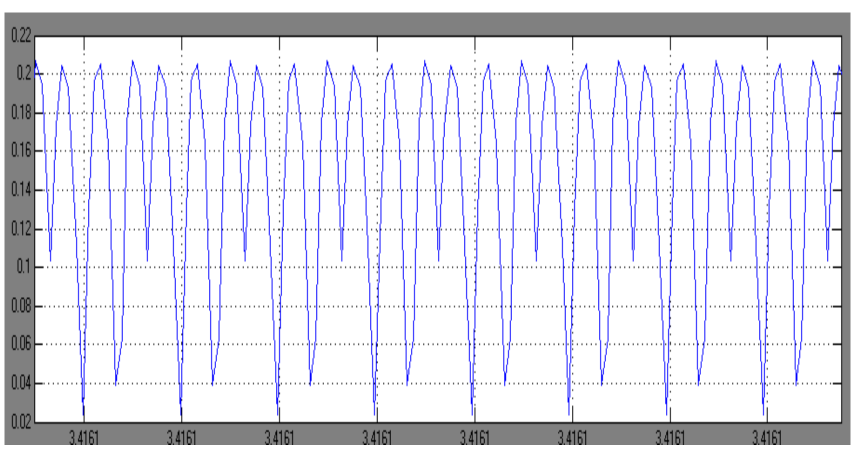


Fig. 30: Enlarge view of output current in period two operation

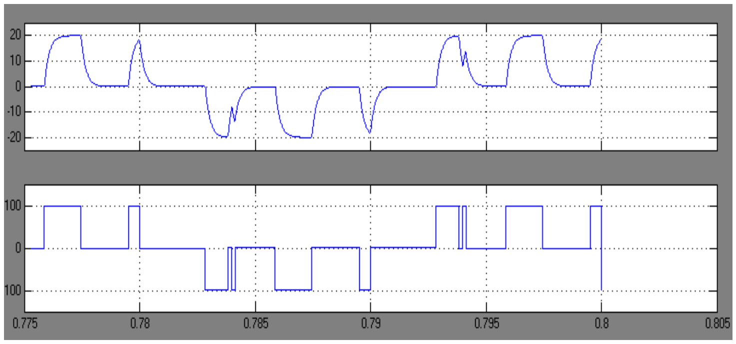


Fig. 31: output voltage and current waveform in unstable state

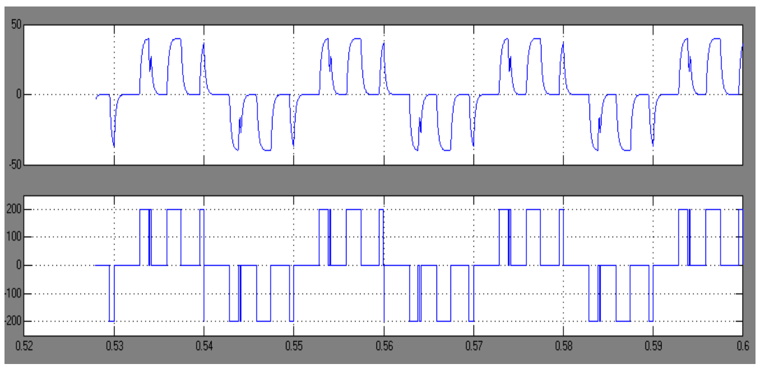


Fig.32: Output voltage and current waveform in unstable state

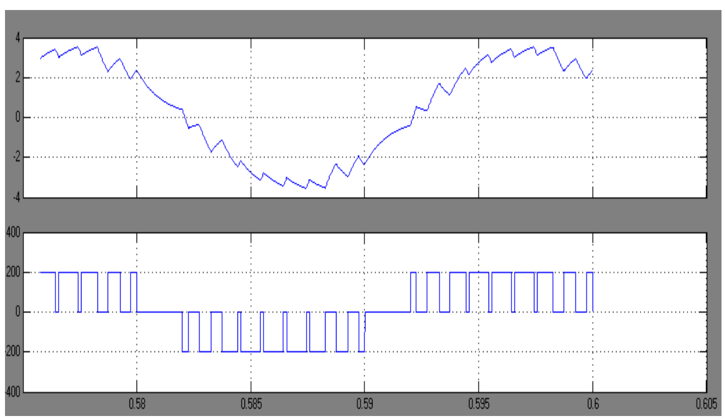


Fig. 33: Enlarge view of output voltage and current waveform in chaotic state

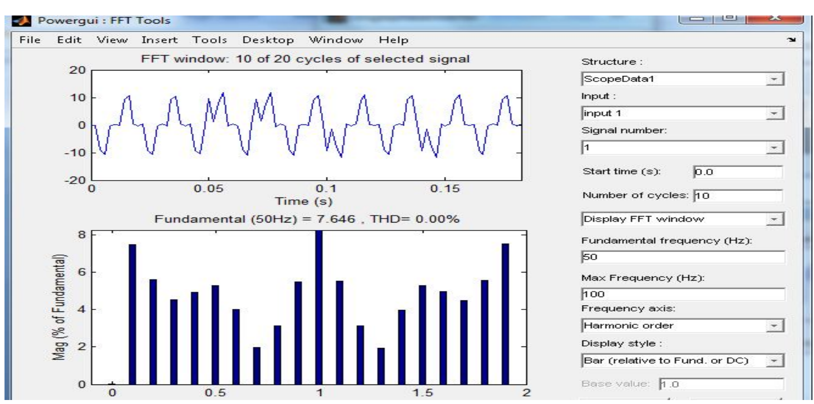


Fig. 34: FFT spectrum of multi stepped inverter for current

Table 8: Thd Of Single And Multi Stepped Inverters

Particular Observation	1-Phase Inverter	Multi Stepped Inverter
THD in % at R= 10Ω	40.96% for V & I	38.16% for V & I
THD in % at R=10Ω,L=0.1mH	36.72% for V & I	48.26%for V 48.31%for I
THD in % at R=10Ω,L=10mH	36.71%for V 55.21%for I	969.65%for V 53.37%for I

Signal 1 and signal 2 are taken for getting current and voltage waveform fast Fourier transform respectively in FFT spectrum of output response. Table 8 provide comparative analysis of different kind of inverters for observing nonlinearity and complex behavior of power inverters.

VI. CONCLUSION

Nonlinear phenomena and complex behavior investigated in the different kinds of power inverters such as single phase, three phase and multi stepped (Eleven stepped inverter) dc to ac power inverter. The inverters shows peculiar and complex behavior as the bifurcation parameter like nature of load and input voltage are changed. Current, voltage waveforms and fast fourier transform spectrum are obtained against various values of output R, R-L load and input supply value, which shows that how inverters approach towards periodic to chaotic mode. The total harmonic distortion for different inverters are obtained and compared for resistive and resistive inductive loads. From the different steps of simulation it is clear that as bifurcation parameter values varies (values of the input voltage, load) the stable orbit undergoes a bifurcation, and the system subsequently approaches to chaotic condition. In Inverter circuits as nonlinearity develops then inverter system tend to move toward complex behavior side. These investigation results provides best knowledge for designing practical circuits before practical implementing of power electronic circuits.

REFERENCES

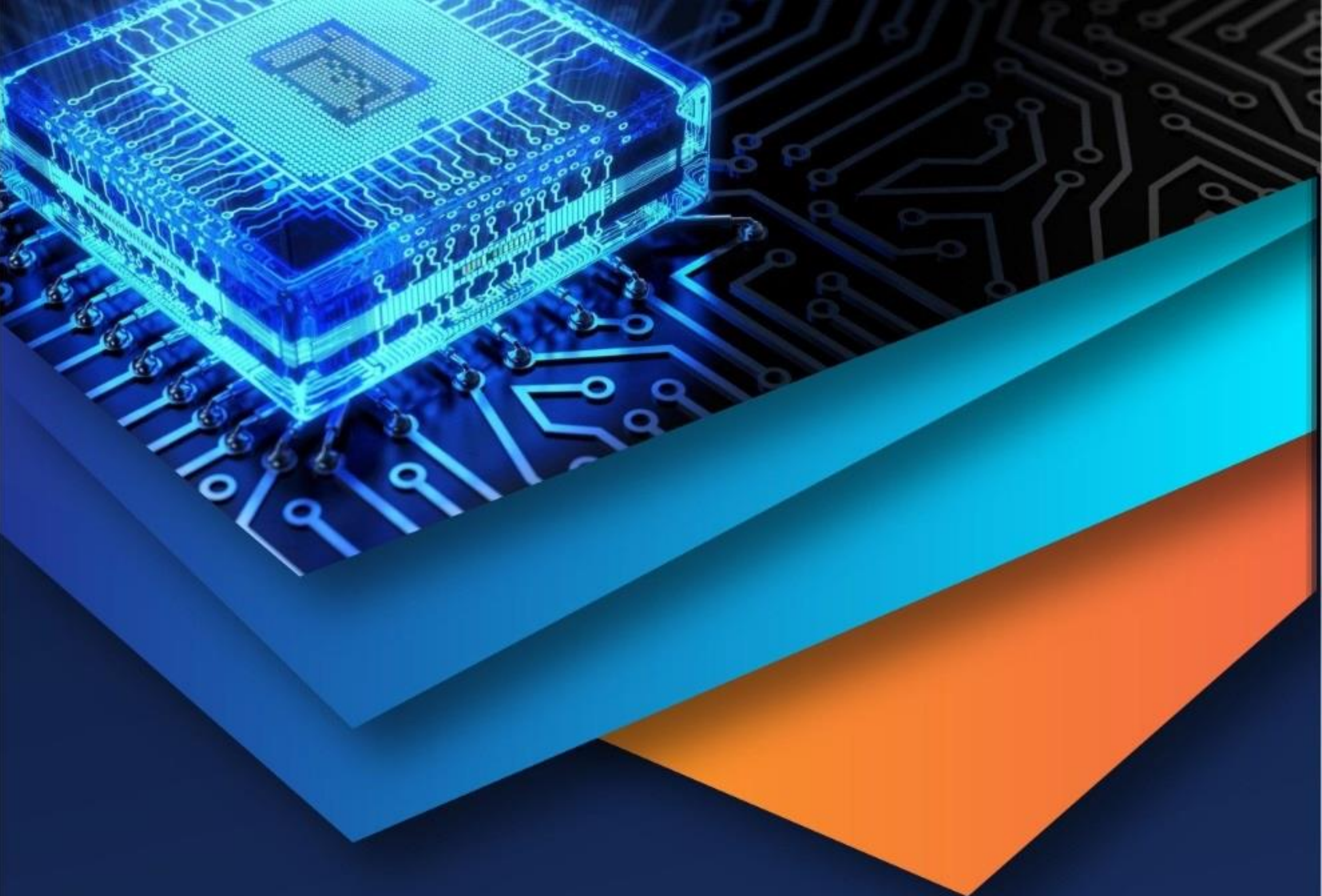
[1] D.C. Hamill and D.J. Jefferies, "Sub-harmonics and chaos in a controlled switched-mode power converter," IEEE Trans. Circ. Syst. I, vol. 35, pp 1059-1061 (1988)
[2] P.T. Krein and R.M. Bass, "Types of instabilities encountered in simple power electronics circuits: unbounded ness, chattering and chaos," IEEE Applied Power Electron. Conf. Exp., pp. 191-194, 1990.
[3] J.H.B. Deane and D.C. Hamill, "*Analysis, simulation and experimental study of chaos in the buck converter*", Power Electronics Specialists Conference Record, vol. II, pp 491-498 (1990)
[4] J.H.B. Deane and D.C. Hamill, "*Chaotic behavior in a current-mode controlled DC-DC converter*", Electronics Letters, vol. 27, no. 13, pp 1172-1173 (1991)
[5] J.H.B. Deane, "*Chaos in a current-mode controlled boost dc-dc converter*", IEEE Transactions on Circuits and Systems, vol. 39 no. 8, pp 680-683 (August 1992)
[6] K. Chakrabarty, G. Podder and S. Banerjee, "Bifurcation behaviour of buck converter," IEEE Trans. Power Electron., vol. 11, pp. 439-447, 1995
[7] E. Fossas and G. Olivar, "Study of chaos in the buck converter," IEEE Trans. Circuit &. System, I, vol. 43, pp. 13-25, 1996.
[8] S. Banerjee, G. C. Verghese ed., "Nonlinear Phenomena in Power Electronics:Attractors, Bifurcations, Chaos, and Nonlinear Control," Wiley-IEEE Press, 2001.
[9] M. di Bernardo, C. K. Tse, "Chaos in Power Electronics: An overview,"Chaos in Circuits and Systems, chapter 16. World Scientific, pp. 317–340, 2002.
[10] H. E. Nusse and J. A. Yorke, "Border-Collision bifurcations including'period two to period three' for piecewise smooth systems," Physica, D57, pp. 39–157, 1992.
[11] H. E.Nusse and J. A. Yorke, "Border-Collision Bifurcations For Piecewise Smooth One-Dimensional Maps," International Journal of Bifurcation and Chaos, *vol. 5-1, pp. 189-207, 1994.*
[12] L. M. Tolbert, F. Z. Peng, and T. G. Habetler, "Multilevel converters for large electric drives," IEEE Trans. Ind. Applicat., vol. 35, pp. 36-44, 1999.
[13] F. Z. Peng and J. S. Lai, "Multilevel Cascade Voltage-source Inverter with Separate DC source," U.S. Patent 5 642 275, June 24, 1997.
[14] N. S. Choi, J. G. Cho, and G. H. Cho, "A general circuit topology of multilevel inverter," in Proc. IEEE PESC'91, 1991, pp. 96–103. 642 275, June 24, 1997.
[15] S.Kumar, G.K.Banerjee,, P.Kumar and R. Kumar, "Study of nonlinear behavior and chaos phenomena in power inverter," in . IJEAS, vol.5, pp 59-65 (2018)

Authors Profile

Sanjeev Kumar graduated from Shri Ram Murti Smarak College of Engineering and Technology, Bareilly India, in 2001, and received his Master's degree in 2006,from the MNNIT ALLAHABAD He is currently working as Assistant Professor in Department of Electrical and Electronics Engineering SRMSCET, Bareilly, He is currently pursuing his Ph.D. from the IFTM University, Moradabad . His research interests include application His main research work focuses on Chaos and bifurcation, dc to dc converter, dc to ac converter and power converters, complex behavior of power electronics systems. He has 17 years of teaching experience. He has several publications in Journals and Conferences in his field. He has attended National Conferences and presented papers there.

Dr.Piush Kumar graduated from Karnataka University Dharwad, in Electrical and Electronics Engineering in 1998 and received his Master's degree in 2003, from M.M.M. Engineering College, Gorakhpur. He did his Ph.D. from MNNIT, Allahabad, India. At present, he is Associate Professor in the Department of Electrical Engineering at Shri Ram Murti College of Engineering and Technology, Bareilly. He has several publications in Journals and Conferences in his field. He has attended National Conferences and presented papers there.

Dr.G.K.Banerjee PhD, is currently Professor and Head, Department of School of Engineering and Technology (SET), Institute of Foreign Trade and Management (IFTM) University, Moradabad. He has been former Professor in the Department of Electrical Engineering, College of Technology, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. Dr. Banerjee has been teaching and conducting research work since last 34 years. He is a member of ISTE and Semi-conductor Society (India).



10.22214/IJRASET

45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY