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Investigation for Avoiding Nonlinearities in DC-AC Power Converters

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ABSTRACT

A study has been carried out for nonlinear phenomena in DC-AC power converters under this paper. High power DC-AC converters are widely used in HVDC and in AC motor drive applications. There are several sources of undesired nonlinearity in practical power inverters. In addition, their operation is characterized through switching thatgenerates a variety of nonlinear dynamics. DC-AC converters controlled by pulse-width modulation (PWM) have been simulated. These converters are simulated using a software package MATLAB SIMULINK. It is observed that the convertersoperation moves from periodic operation to chaotic operation as the output load to the converter is changed as load considered as bifurcation parameter. The voltage, currentwaveforms and FFT analysis obtained from the circuit simulation have been studied. The bifurcation pathway includes smooth period-doubling bifurcations as well as border collision bifurcations. Simulated results are validated with experimental results. Both are found in good agreement to each other. This knowledge is playing very powerful role for designing practical circuits in power electronics based system.
Keywords : Nonlinearities, Bifurcation, Dc to Ac Converter, Chaotic State.

I. INTRODUCTION

Theory of nonlinear system is one of the most important natural sciences exploited in the 20th century and it has been increased into the researches for many types of issues. Power electronics systems have strong nonlinearity because there are semiconductor switch devices implemented in them.

The occurrence of bifurcations and chaos in power electronics was first reported in the literature by Hamill [1] in 1988. Experimental observations regarding bounded ness, chattering and chaos were also made by Krein and Bass [2] back in 1990. Although these early Investigations did not presents any rigorous and detailed analysis, they provided strong evidence of the importance of studying the complex behavior of power electronics and its possible benefits for practical design in power electronic system. Utilizing an implicit iterative map, the phenomena of occurrence 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 derivation of a closed-form iterative map for the boost converter under a current-mode control scheme was presented later by the same group of researchers [4, 5].

So they can be arranged as a kind of nonlinear system and naturally can be studied from the nonlinear system theory. Power electronic circuits are also used extensively in actual, so the research on them is essential. The research on complex nonlinear behavior in power electronic circuits began in the 1980s and many kinds of possible phenomena in common nonlinear system have been found, such as diverse bifurcations leading to chaos, complex intermittency, attractors coexistence, devil's staircase, fractal attractors, etc [6-9]. In recent years, the research tasks have changed from disclosing the possible phenomena to the control of the phenomena, so as to design stable circuits or improve circuit performance. In the past 20 years, DC-DC converters were the main objects in the study of nonlinear phenomena of power electronic circuits, simultaneously few other types of the power electronics circuits are studied. But in recent years, breakthroughs are obtained, such as Robert firstly examined the bifurcation and chaos phenomena in the proportional controlled H Bridge inverter which belongs to the inverter circuit [9-11]. H bridge voltage and current double closed loop feedback control inverter is widely used due to its good characteristics such as over-current protection, fast transient response, parallel operation, etc. But it will give birth to fast-scale bifurcation and chaos due to the variation of the system parameters, and the voltage and current ripple will increase, accordingly presents a worsen working performance of the circuit. So it is important to give aneffective way for suppressing the bifurcation and chaotic behavior [11-12].

All types of power electronics 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 avoid these phenomena it is very important to predict and analyze these nonlinear phenomena of a converter.

In reality, bifurcation is to be avoided, but it is also known that designing a system too remote from bifurcation boundaries may degrade performance characteristics. Hence, efforts have been made to study the bifurcation behavior of a single phase and three phase dc to ac converter and cascaded nine levels H-bridge inverter to show the practical relevance of bifurcations and chaos in power electronics systems. The first stage of the converter is a single phase and three phase a dc to ac converter, to provide Ac from battery source and to vary the load parameter as bifurcation parameter. In second stage, the Nine level cascaded multilevel dc to ac converter with single phase h – bridge converter. The dc to ac converter has variable load parameter on fixed input voltage. The converter is simulated on a software package MATLAB/SIMULINK. Current and voltage waveforms obtained with change in load parameter values.

II. CAUSES TO GENERATE UNWANTED NONLINEARITY:

There are many unavoidable sources of undesired Nonlinearity in practical power electronics circuits:

1. The semiconductor elements and switching devices have intrinsicallynonlinear DC characteristics: BJTs, MSOFETs, IGBTs, thyristors, diodes.
2. They also have nonlinear capacitances, and most sufferfrom minority carrier charge storage.
3. Nonlinear inductances abound: transformers, chokes, ferroresonant controllers, magnetic amplifiers and transconductors, and saturable snubber inductors.
4. The control circuits normally involve nonlinearcomponents: comparators, pulse-width modulators (PWMs), multipliers, phase-locked loops (PLLs), monostables (autonomous timers) and digital controllers.

This paper concerned with Dc to Ac power converters behavior investigation, which by virtue of their High contents of nonlinearity exhibit a variety of complex behavior of power electronic systems.

III. NONLINEARTIES IN DC-AC CONVERTERS

As shown in Figure 1, the main circuit of an H bridge inverter fed with a DC power E, includes switches SW1 _ SW4 (with the reverse parallel diode), and load.

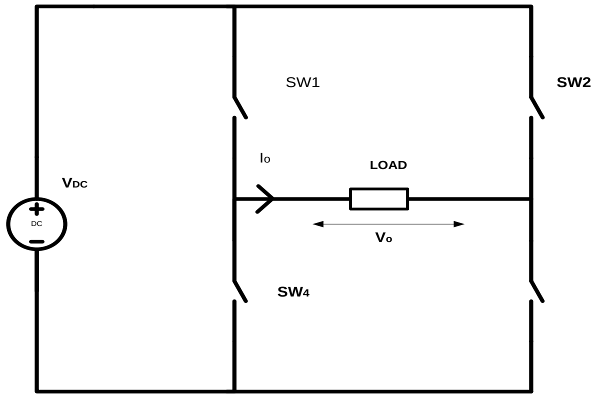

Figure 1. BasicCircuit of H-bridge inverter

This circuit is easily realized by four switches, a voltage source, an inductor and a resistor. The four switches are named by SW_1, SW_2, SW_3, and SW_4. This circuit has the following two conditions with the controller.

State A: SW1 and SW2: OFFSW3 and SW4: ON.

State B: SW1and SW2: ON SW3 and SW4: OFF.

The circuit dynamics is described by

Table 1. Circuit dynamics of inverter system

$\frac{di}{dt}$	State-A	State-B
	$-\frac{R}{L}i \quad -\frac{E}{L}$	$-\frac{R}{L}i \quad +\frac{E}{L}$

Table 2. Switching pattern of conventional topology

S_1 & S_2	S_3 & S_4	Output Voltage(Vo)
1	*0*	*+Vdc*
0	*1*	*-Vdc*

For obtaining nonlinearities in different dc-ac converter i.e. Inverter load is to be considered as bifurcation parameter. Different simulation results obtained as load changes as a bifurcation parameter

IV. DETERMINATION OF SWITCHING AGLES

For phase delay Values can be obtained as follows

$$PHASE\ ANGLE\ DELAY = \frac{FIRING\ ANGLE}{2\pi} * TIME\ PEROD$$

For frequency 50Hz Time period given by

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

Time period is 20ms. Therefore for delay angle for switch to turn converter

Time Period 0.02 sec=360^0

So 1^0 = 0.02/360

For 60^0 = (0.02/360)*60

Source block parameters for pulse generator 1and 2 are:

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

V. PHASE DELAYS FOR THREE LEVEL SINGLE PHASE H-BRIDGE INVERTER:

These delay angles provided to pulse generator 1, 2 blocks for 3 level inverter.

$$\theta 1 = \text{Phase delay of S1,S3} = \frac{9^0}{360^0} * 0.02$$

$$\theta 1 = \text{Phase delay of S1,S3} = 0.0005$$

$$\theta 2 = \text{Phase delay of S2,S4} = \frac{189^0}{360^0} * 0.02$$

$$\theta 2 = \text{Phase delay of S2,S4} = 0.0105$$

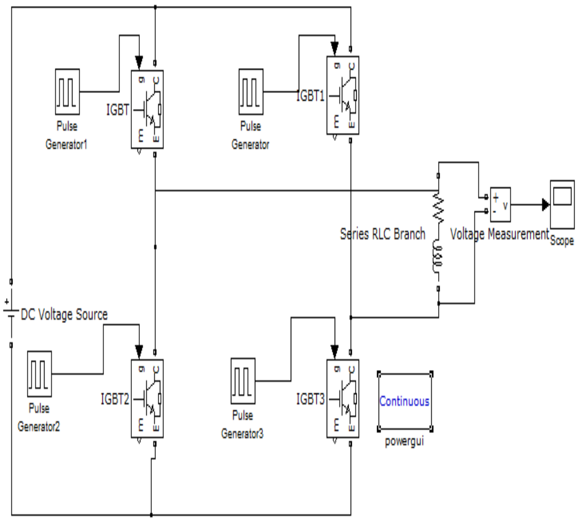

Figure 2. Simulink Model of single phase inverter

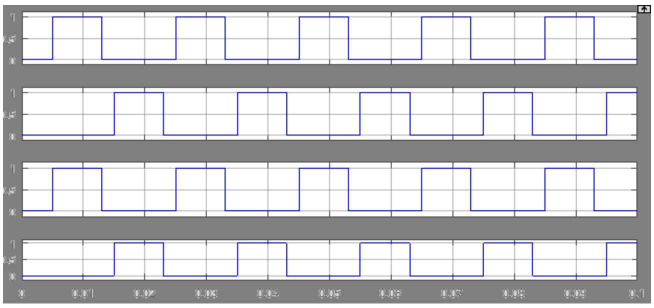

Figure 3. Switching pulses waveforms from S1 to S4 of H Bridge Inverter

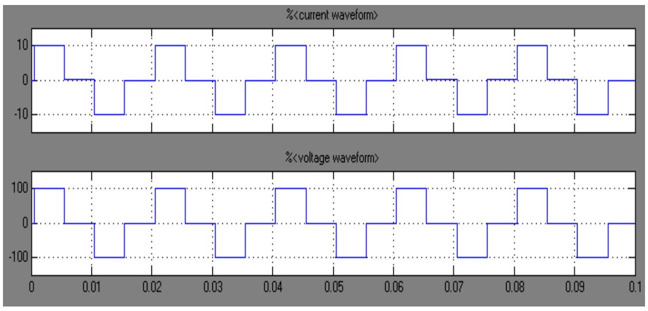

Figure 4. Output Voltage and current Waveform of H Bridge Inverter with Rload

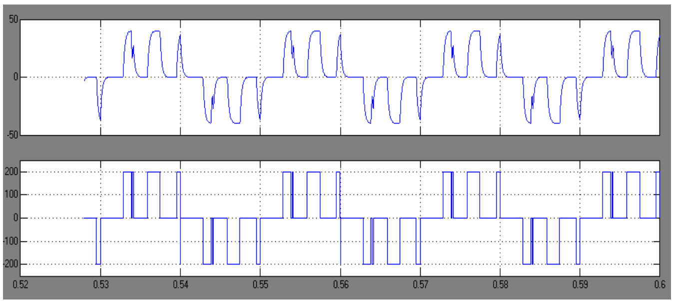

Figure 5. Distorted Current/Voltage waveform.

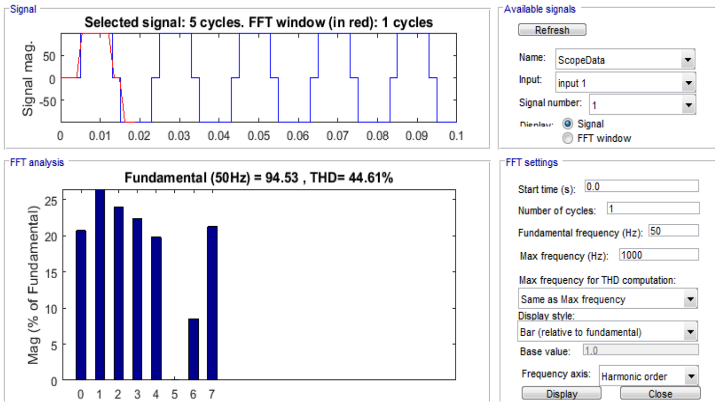

Figure 6. FFT spectrum of three level inverter for voltage on R load

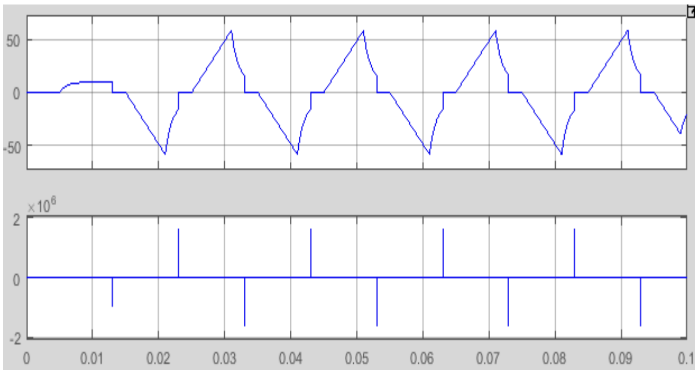

Figure 7. Simulation result of three level inverter on R=10Ω &L=10mH

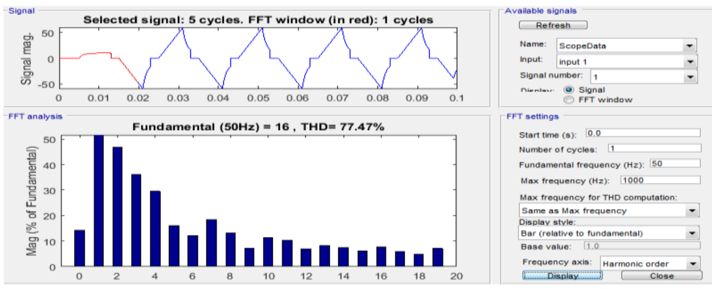

Figure 8. FFT spectrum of three level inverter for voltage on R=10Ω & L=10mH

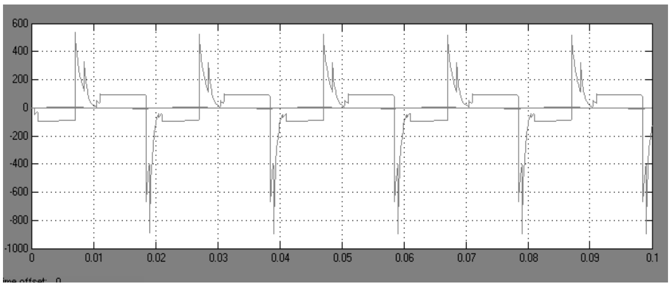

Figure 9. Inductor current period-2 operation R=1000 L=100h

Output Voltage and current waveform of single phase H Bridge Inverter with R-load shown in figure 4 which shows linear behavior (period-1) of system. Figure 7 shows distortion in voltage and current waveform on R-L load and FFT spectrum shows THD 77.47% which indicates that converter moving towards chaotic mode through bifurcation path way. Same operation justified on R=1000Ohm and L=100H through inductor current waveform

VI. NONLINEARTIESIN THREE PHASE DC-AC CONVERTERS

To provide adjustable- frequency power to industrial applications, three phase inverter are more common than single phase inverters

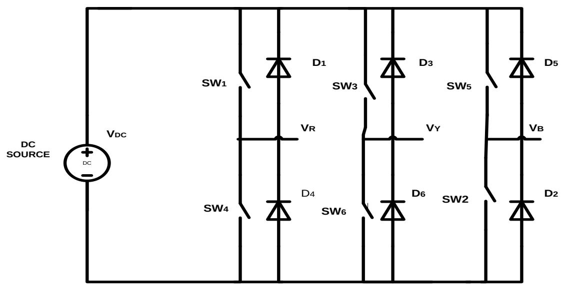

Figure 8. Circuit diagram of three phase inverter

A: Operation Table:

Table 3. Switching pattern of conventional topology

S.No.	Firing Interval	Turn-on devices	Conducting devices
1	0^o-60^o	S_1	S_5 S_6 S_1
2	60^o-120^o	S_2	S_6S_1 S_2
3	120^o-180^o	S_3	S_1 S_2 S_3
4	180^o-240^o	S_4	S_2 S_3 S_4
5	240^o-300^o	S_5	S_3 S_4 S_5
6	300^o-360^o	S_6	S_4S_5 S_6

B. Working

Switch pair in each leg, i.e. S_1, S_2, S_3, S_4, S_5, S_6 are turned-on with a time interval of 180^o .It meansthat switches S_1 conduct for 180^o and switch S_4 for the next 180^o of a cycle. Switches, in the upper group, i.e. S_1 S_3, S_5 conduct at an interval of 120^o. It means that if S_1 is fired at 0^o, than S_3 must be triggered at 120^o and S_5 at 240^o.Same is true for lower group of switches.

The three line output voltages can be described by the Fourier series as:

$$V_{ab} = \sum_{n=1,3,5}^{\infty} \frac{4Vs}{n\pi} cos\frac{n\pi}{6} \sin n\left(\omega t + \frac{\pi}{6}\right) \quad (1)$$

$$V_{bc} = \sum_{n=1,3,5}^{\infty} \frac{4Vs}{n\pi} \cos\frac{n\pi}{6} \sin n\left(\omega t - \frac{\pi}{2}\right) \quad (2)$$

$$V_{ca} = \sum_{n=1,3,5}^{\infty} \frac{4Vs}{n\pi} cos\frac{n\pi}{6} \sin n\left(\omega t + \frac{5\pi}{6}\right) \quad (3)$$

For n=3, $\cos 90^0=0$.Thus all triplen harmonics are absent from line voltage.

The line voltage $V_{ab} = V_{ao} + V_{ob}$

or $Vab = V_{ao} - V_{bo}$ (4)

Similarly V_{bc}&V_{ca} can be obtained.

Fourier series expansion of line to neutral voltage Vao in output voltage waveform is given as

$$V_{an} = \sum_{n=6k+1}^{\infty} \frac{2Vs}{n\pi} \sin n\omega t \quad (5)$$

Where k = 0, 1, 2…..

C: Different Modes:

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.
4) From the table, it is observed that in every step of 60^o duration, only three switches are conducting.
5) The output voltage waveform are quasi square wave with a peak value of V_s.
6) The three phase voltages V_{AN}, V_{BN} and V_{CN} are six step waves with step heights of $V_s/3$ and $(2/3)V_s$.
7) Line voltage V_{AB} is leading the phase voltage V_{AN} by 30^o.

D. Simulink Model &parameter selection:

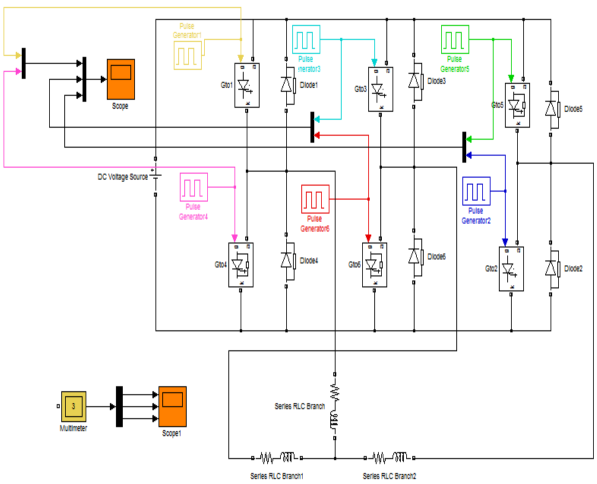

Figure 9. Simulink model of three level inverter

Parameter selection for switching of inverter switch

In order to trigger the dc to ac converter switching devices give proper triggering pulses to it using a pulse generator. Desired values can be enter in the block which is obtained by double clicking pulse generator .The Pulse Generator block generates square wave pulses at regular intervals. This square wave pulses are applied to the converter for triggering. The block's waveform parameters, Amplitude, Pulse Width, Period, and Phase Delay determine the shape of the output waveform.

Values for phase delay can be obtained as follows

0.6 sec=360^0

1^0=0.6/360

60^0= (0.6/360)*60

Table 4. Showing the specifications for different pulse generator:

Pulse generator	Delay in degree	Amplitude	Periods (sec)	Pulse width (% of period)	Phase delay (sec)
1	0	3	0.6	50	0
2	60	2	0.6	50	0.1
3	120	2.5	0.6	50	0.2
4	180	3	0.6	50	0.3
5	240	2	0.6	50	0.4
6	300	2.5	0.6	50	0.5

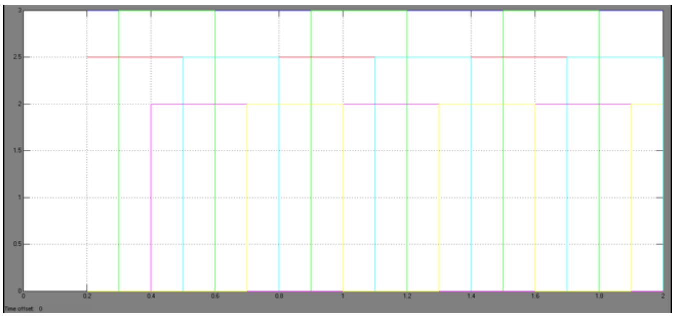

Figure 10. Switching pulses waveforms from S1 to S6 of H Bridge three phase Inverter

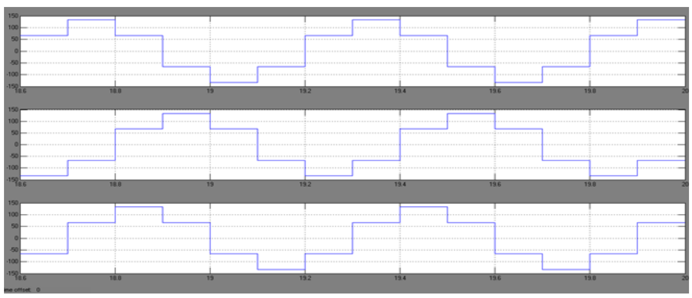

Figure 11. Voltage waveforms of three phase inverter with resistive load

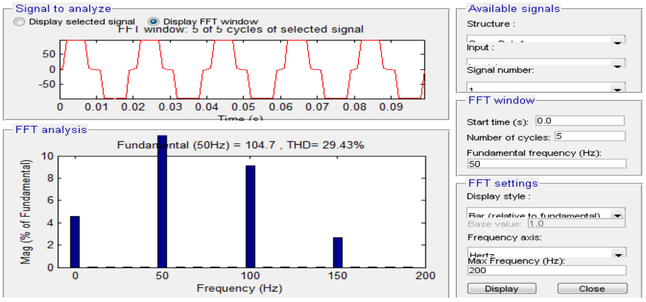

Figure 12. FFT spectrum of three phase inverter for voltage

The FFT analysis is done for voltage to study the reduction in harmonics and corresponding spectrum is shown in Figure 12.

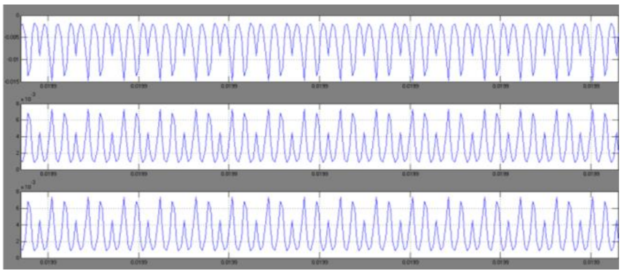

Figure 13. Distorted load current after variation in Load

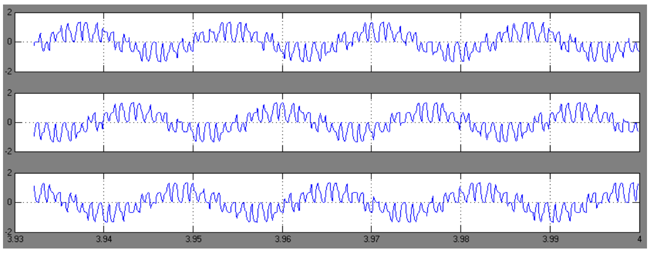

Figure 14. Distorted output waveform of load current after variation in Load

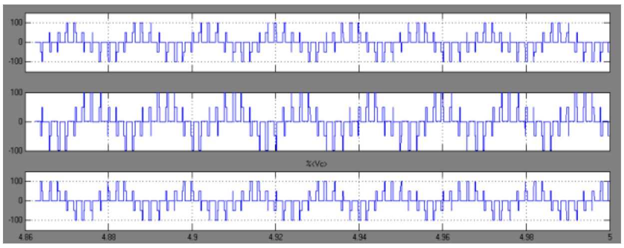

Figure15. Distorted Voltage waveform of Three Phase Inverter at R-=100ohm ,L=10mh , modulaion index=0.75

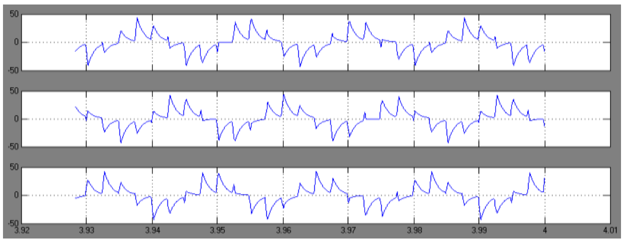

Figure 16. Chaotic mode Output Current Waveform of three phase Power Bridge Inverter

The FFT analysis is done for voltage to study the reduction in harmonics and corresponding spectrum is shown above in figure 12.In figures from Figure 13 to Figure 16 output distorted voltage and current waveforms shows nonlinear behavior after varying load as bifurcation parameter

VII. NONLINEARTIES IN CASCADED MULTI LEVEL DC-AC CONVERTERS

The difference between a simple inverter and a multilevel inverter is as follows:

1) Multilevel inverters give higher power

2) They are operated through multiple switches instead of one

3) They can use environmental friendly energies like wind and solar energy and
Convert them to AC.

A multilevel inverter is a power electronic device which is capable of providing desired alternating voltage level at the output using multiple lower level DC voltages as an input.
Multilevel voltage-source inverters provide a cost-effective solution in the medium-range voltage energy management system. These cascaded multilevel converters have been widely used in chemical, oil, and liquefied natural gas (LNG) plants, energy transmission, water plants, marine propulsion, power generation and power-quality devices.

Presently, there exist three commercial topologies of multilevel voltage-source inverters: flying capacitors

(FCs), neutral point clamped (NPC) and cascaded H-bridge (CHB). Among all these dc to ac inverter topologies, cascaded multilevel inverter obtains the higher output voltage and power levels (13.8 kilo Volt, 30 MVA) and the top level reliability due to its effective modular topology.

Cascaded multilevel dc to ac inverters are based on a series connection of several single-phase H-bridge inverters. This kind of construction is capable of reaching moderate range of output voltage levels using only standard low-voltage mature technology components. Typically, it is necessary to cascade three to ten inverters in series to obtain the required output voltage level.

These converters also feature a high quality of modularity degree due to each inverter can be seen as a module with similar circuit topology, control structure, and modulation. Therefore, in the case of any kind of fault in one of these modules, it is possible to replace it fastely and easily. Moreover, with an appropriated control strategy, it is possible to bypass the faulty module without stopping the load, bringing an almost continuous overall availability

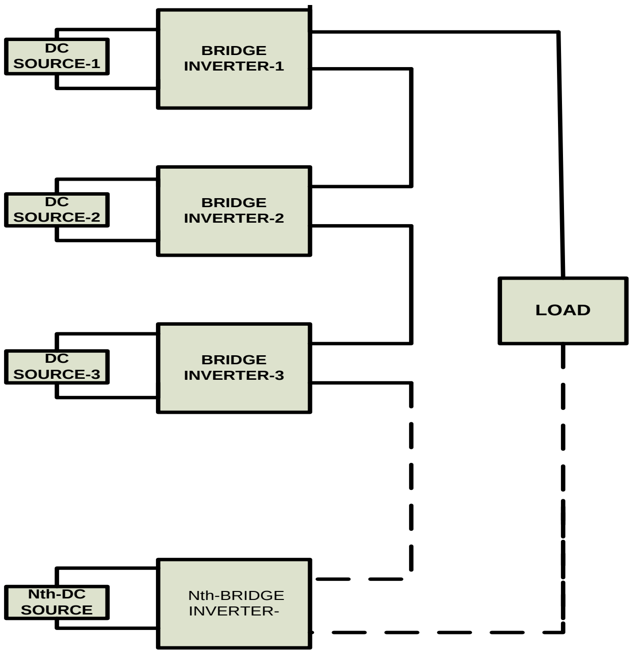

Figure 18. Block diagram of N-level inverter

The Phase voltage

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

For a stepped waveform such as shown in Figure 31.2 with five steps, The Fourier Transform for this wave form follows:

$$V(\omega t) = \sum_{n=1,3,5,..}^{\infty} * \frac{4Vdc}{\prod n}[Cos(n\theta 1) + Cos(n\theta 2) + \cdots + Cos(n\theta s) \quad (2)$$

Where n=1, 3, 5, 7, 9….

From eq. (2) the magnitude of Fourier coefficients when normalized with respect to V_{dc} are as follows:

$$H(n) = \frac{4}{n\pi}[Cos(n\theta 1) + Cos(n\theta 2) + Cos(n\theta 3) + \cdots Cos(n\theta s)] \quad (3)$$

Where n=1, 3, 5, 7, 9….

The conduction angles, $\theta 1, \theta 2, \theta 3, \theta 4 \ldots\ldots..\theta s$, can be chosen such that the voltage THD is a minimum.

Generally, these angles are chosen so that predominant lower frequency harmonics,5^{th},7^{th} ,11^{th}, and 13^{th} ,harmonics are eliminated

In order to reduce the complexity of multilevel inverter a subsystem of single phase H bridge inverter created as shown Figure 19.By using this it is simple to design high power multi-level on single working window. Below Figure 20 shows Simulink model of subsystem

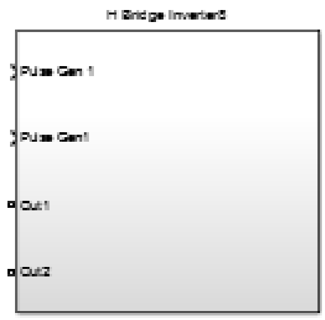

Figure 19. Simulink model of subsystem

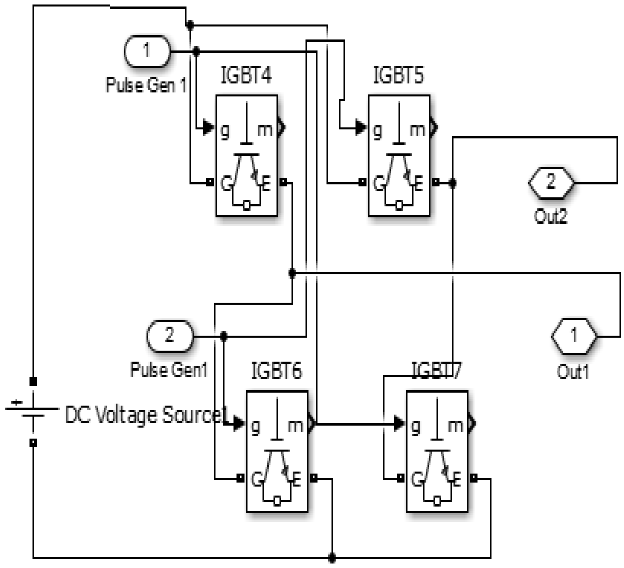

Figure 20. Internal Simulink model of subsystem for Bridge circuit

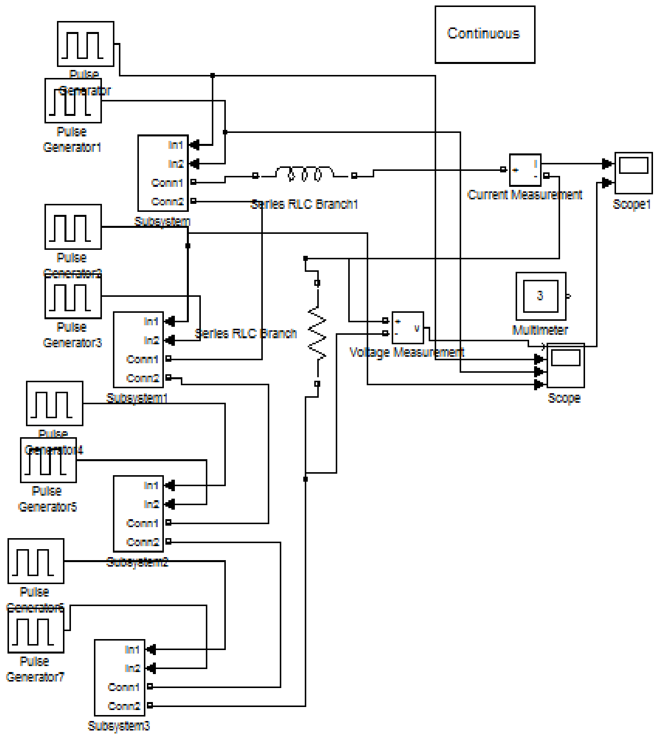

Figure 21. Simulink design model of single phase ninelevel cascaded H bridge inverter

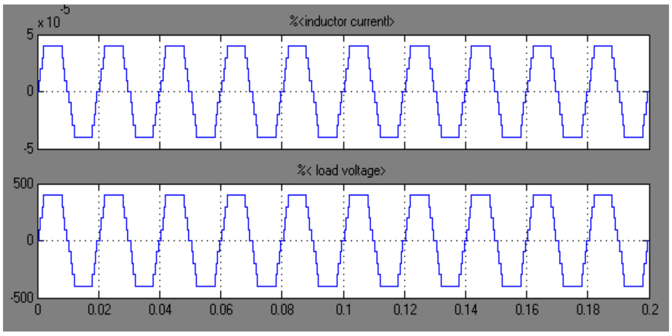

Figure 22. Voltage & inductor current waveform of single phase nine level cascaded H bridge inverter

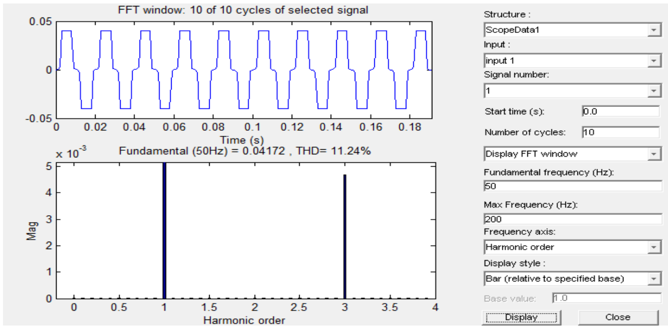

Figure 23. FFT spectrum of nine level inverter for voltage

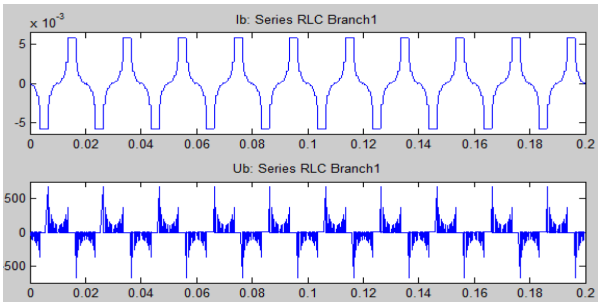

Figure 24. Chaotic Output Current Waveform of nine level Inverter

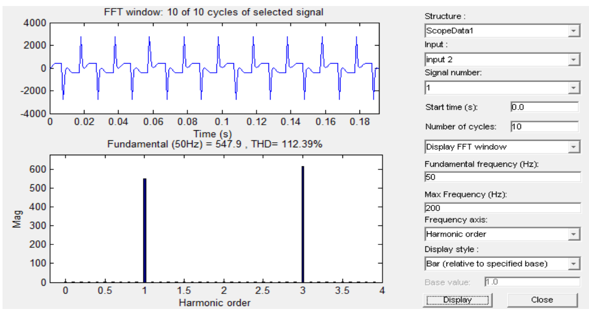

Figure 25. FFT spectrum of nine level inverter at R=10KΩ, L=650mH for voltage waveform

Designing of Phase Delays for Nine-Level single phase H-Bridge inverter:

These phase delay (p.d.) angles provided to pulse generator 1, 2, 3,4, 5,6 and 7,8 blocks for 9 level inverter.

θ 1 = P.d. of S1,S3 = $\frac{9^0}{360^0}$*0.02 =0.0005,

θ 2 = P.d. of S2,S4 = $\frac{189^0}{360^0}$*0.02 =0.0105

θ 3 = P.d. of S1,S3= $\frac{18^0}{360^0}$*0.02 = 0.001

θ 4 = P.d. of S2,S4= $\frac{198^0}{360^0}$*0.02 =0.0110

θ 5 = P.d. of S1,S3= $\frac{27^0}{360^0}$*0.02 = 0.0015

θ 6 = P.d. of S2,S4= $\frac{207^0}{360^0}$*0.02 =0.0115

θ7 = P.d. of S1, S3= $\frac{36^0}{360^0}$*0.02 = 0.0020

θ 8 = P.d. of S2,S4 = $\frac{216^0}{360^0}$*0.02 =0.0120

Table 5. Phase delay of, nine level inverters

BRIDGE/PHASE DELAY	θ_1	θ_2	θ_3	θ_4
BRIDGE-1	0.0005	0.0105	0.0005	0.0105
BRIDGE-2	0.001	0.0110	0.001	0.0110
BRIDGE-3	0.0015	0.0115	0.0015	0.0115
BRIDGE-4	0.0020	0.0120	0.0020	0.0120

VIII. CONCLUSION

Single phase and three phase nine level switching inverter have been simulated in mat lab/Simulink. From simulation results it is obtained that different level inverter moves toward chaotic region from stable state as load varies as bifurcation parameter. These inverters have wide industrial application so it is necessary for the design engineers to have a comprehensive knowledge about the circuit behavior at different regions of parameter space. It is often difficult for the novice to grasp the fundamental concepts of nonlinear dynamics when they were represented in overly mathematical terms. But simulations of circuit of nonlinear power electronics circuits allow hands-on experience of chaotic behavior in a user friendly environment with graphical output. The learning process is also enhanced by the ability to modify and experiment with the circuit parameters at will. The practical advantage of studying chaos is a better understanding of the chaotic behavior of DC-AC converters that will lead to more reliable designs and new possibilities of operating regimes that can help optimize design.

IX. REFERENCES

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