Avoiding Complex and Nonlinear Behaviour of Multilevel Power Inverter

Sanjeev Kumar, Anil Kumar, Piush Kumar

***Abstract:** In the present scenario to meet out the goal, recent technology of multilevel inverter has introduced which helps to provide a very useful alternative in the field of huge power and a moderate range of voltage applications. Under this work, an attempt has been made to study the complex nature due to nonlinearities and chaos in cascaded multilevel dc to the ac converter system. Nonlinear behavior phenomena are observed in three-phase inverter and cascaded multilevel H-bridge inverter using Matlab / Simulink software package. By various observations, it is reported that the dc to ac converter shifted their position from a stable operating condition to unstable operating conditions as the bifurcation parameter like load varied for the power inverter system. Simulation results obtained through software Matlab / Simulink demonstrate output voltage and current waveform of inverter along with its FFT spectrum. This study for getting information about the nonlinear behavior of power multilevel inverter system is playing a very vital role in designing and fabrication of practical circuits in the power electronics field.*

***Keywords:** Nonlinearities, Multilevel power inverter, H-Bridge, Total harmonic distortion (THD)*

I. INTRODUCTION

The nonlinear system theory is one of the very popular theories among researches for many types of issues. All kinds of Power electronics systems have strong nonlinearity because there are semiconductor switching devices implemented in them. The occurrence and presence of bifurcations and chaos phenomena in power electronics systems were firstly observed in the literature by Hamill [1] in 1988. Experimental investigations through practically implemented circuits related to boundness, chattering, and chaos were also made by Krein and Bass [2] back in 1990. Although these previous investigations did not present any typical and more detailed analysis, they provided strong and powerful evidence of the practical signification of studying the complex nature of power electronics devices and all its possible advantages for practical design in the power electronic system.

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Utilizing an implicit iterative map, the phenomena of occurrence of period-doublings, sub-harmonics and chaos in a simple dc to dc buck converter were observed and demonstrated by Hamill [3] using PSPICE simulation, numerical analysis, and laboratory measurements. The derivation of a closed-form iterative map further discussed by a group of researchers [4, 5].

So they can be arranged as a kind of nonlinear system and nature can be studied from the nonlinear system theory. Power electronic circuit's most useful and important natural sciences exploited are also used extensively in actual, so the research on them is essential. The research on complicated nonlinear behavior in power electronic circuits began in the 1980s and many kinds of possible phenomena in common nonlinear systems have been found, such as diverse bifurcations leading to chaos, complex intermittency, attract coexistence, devil's staircase, fractal attractors, etc [6-9]. In recent years, research tasks have changed from disclosing the possible phenomena to the control of the phenomena, to design stable circuits or improve circuit performance. In the past 20 years, DC-DC converters were the main objects in the observation, analysis, and investigation of nonlinear phenomena of power electronic circuits, simultaneously few other types of power electronics circuits are studied. But in recent years, a breakthrough is 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 are 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 poor working performance of the circuit. So it is important to give an effective way of suppressing the bifurcation and chaotic behavior [11-12].

All various kinds of power electronics dc-ac converters may be configured like nonlinear time-varying dynamical systems as they exhibit a wealth of nonlinear phenomena, in addition to different types of bifurcations and chaos. The potential cause of non-linearity is the inherent switching action in the system and existence of nonlinear devices (e.g. the power diodes) and control techniques (e.g. pulse-width modulation). These nonlinearities are the main source of malfunction and failure in engineering applications. Therefore to neglect and remove these types of phenomena it is a very essential requirement to analyze and predict these nonlinear phenomena for the converters.

As a general rule, bifurcation is to be ignored and kept away from, yet it is likewise realized that forming a power hardware circuits excessively remote from bifurcation limits may degrade the standard and performance quality of attributes. Therefore, attempts have been made to study and analyze the complex behavior and nature of bifurcation of a single-phase and three-phase dc to ac converter.

Eleven levels of cascaded H-bridge inverter demonstrate the practical relevance of bifurcations and chaos phenomena in power electronics circuits. The first primary state of the inverter is a single phase and three phases a dc to ac converter, to provide ac from battery source and to vary the load as the bifurcation parameter. The second stage consists of, the eleven levels single and three phases cascaded multilevel dc to ac converter with single-phase H – bridge converter. The dc to ac converter has a variable load parameter on the fixed input voltage. The converter is simulated on a software package MATLAB/SIMULINK. In simulation results at output load current and voltage waveforms obtained with the change in load parameter values.

II. DIFFERENT CAUSES OF UNWANTED NON LINEARITY

There are many unavoidable sources of the undesired quantity of nonlinearity in most of the practical power electronics circuits. Some of that commonly occur are as follows.

- All the semiconductor elements and switching components have intrinsically nonlinear DC characteristics: BJTs, MOSFETs, IGBTs, thyristors, diodes.
- . They also have nonlinear capacitances, and most suffer from minority charge storage carriers.
- Nonlinear inductances abound transformers, chokes, Ferro resonant controllers, magnetic amplifiers and Trans conductors, and saturable snubber inductors.
- 4. The nonlinear components: comparators, pulse-width modulators (PWMs), multipliers, monostable (autonomous timers) and digital controllers are usually part of control circuits.

Research work under this paper focused on multi-level Dc to Ac power converters behavior complexity investigation by variation of load, which under their High contents of nonlinearity exhibits various types of complex and typical nature of power electronic systems.

III. PHENOMENA OF BIFURCATION AND CHAOTIC BEHAVIOR

By variation, a qualitative change in the dynamics, which occurs when a system parameter is varied, is known as bifurcation. A convenient and effective method of studying bifurcation is through a bifurcation diagram. A dynamical system can have many equilibrium solutions, for a given pair of parameter values and primary position the dynamical system approaches one of the equilibrium solutions. This equilibrium solution is called an attractor. If the parameters are permitted to change, the system may relinquish its existing assumed equilibrium solution and gets other equilibrium solution. For instance, the parameter changes, the currently assumed equilibrium solution reaches unstable condition and the system is attracted to other stable equilibrium solutions. This phenomenon is known as bifurcation.

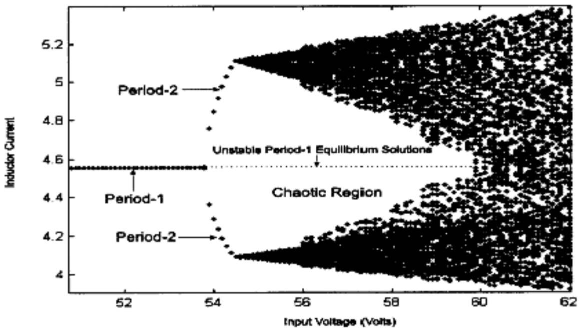

Fig.1.Numerically obtained the bifurcation diagram of the converter.

Fig.1 illustrates the Bifurcation diagram of a converter system. There is three number of variable consider as bifurcation parameter in the circuit the input voltage (Vin), the load (RL) and the inductance L

- V_{in} (Input Voltage)
- R_L (load-resistance)
- L (Inductance)
- Amplitude and frequency of triangular wave-like as the bifurcation parameter

For identifying how a system's qualitative behavior varies as some selected parameters are changed bifurcation diagrams are frequently used. To show a bifurcation diagram, we require constructing and designing a system that produces the essential signals to the oscilloscope for displaying a bifurcation diagram.

In the chaotic mode of operation controlled dc-ac converter, the system states as remains bounded within a fixed volume in the state space. But similar states repeat never. In every loop through by the state space, the state traverses a new trajectory. This status is called chaos and the obtained final attractor is known as a strange attractor. In other words, if an attractor consists of infinite points bounded within a fixed region of the state space the overall behavior is known as Chaos. This Chaotic behavior is the aperiodic behavior of a system.

Discrete-time systems, whether generated by data sampling or otherwise, are arguably even more prone to chaos than continuous-time systems, where the dynamics must be of at least third-order (in the case of single-valued nonlinearities) for such behavior to perform. Indeed a simple first-order recurrence relation of the form

$$x(t+1) = \mu f\left(x(t)\right) \tag{1}$$

Here f(x) is a smooth function and μ is a scalar parameter, which

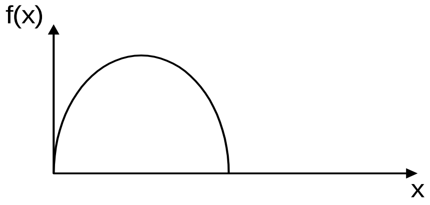

Fig.2.A single-humped function

can exhibit an extremely complicated solution, which may also be remarkably sensitive to both the initial state and the value of μ. A widely studied case is the so-called 'logistic equation' obtaining by setting

$$f(x) = x - x^2 \qquad (2)$$

Although similar behavior is found whenever f(x) has the same kind of humped shape.

In this particular case, what happens is as follows. For 0<μ<1, the equilibrium point at the origin, which always exists, is stable and there is an unstable and at x=1-(1/μ).Where μ exceeds unity, the origin becomes unstable; the other equilibrium point, now in the region x> 0, becomes stable and remains so for 1<μ<3 at μ = 3, a phenomena are known as 'period-doubling bifurcation' occurs in which this equilibrium(regarded as a limit cycle of period-1) converges unstable and a period 2 stable cycle appears.

Then, as μ is further increased, this process is repeated, successively generating cycles with periods 4, 8, 16, the bifurcation being ever more closely spaced in μ. Until an accumulation, the point is reached at μ nearly equal to 3.57. Above this value, limit cycles of odd periods appear and also bifurcate, until eventually all periods are represented although, for any given value of μ only one cycle is stable is always present (except at isolated values of μ) but, from a practical viewpoint, the effect is much the same, as a finite length simulation is incapable of distinguishing a cycle of sufficiently long period from a periodic solution.

The " routs to chaos" described here are often illustrated utilizing the bifurcation diagram, in which the fixed points of the iterated mappings defined by repeated applications of the recurrence relation, are plotted against the parameter μ. There are two main kinds of bifurcation involved, known as the "Pitchfork" and "Tangent" types as shown Fig.3 and Fig.4

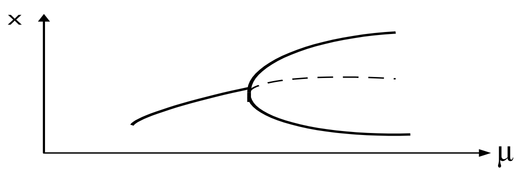

Fig.3. Pitchfork Bifurcation

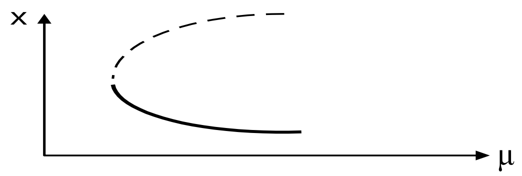

Fig.4: Tangent Bifurcation.

With solid lines denoting stable points (or points on stable cycles) and dotted lines indicating unstable ones. In the pitchfork bifurcation, a stable point or cycle is replaced, at some value of μ, by a pair of points on a stable cycle of twice the period, together with an unstable solution; this is the period-doubling phenomena mentioned above. At the tangent bifurcation, two new points or cycles appear simultaneously, one being stable and other unstable. Typically, the approach to chaos involves multiple tangent bifurcations, each being followed by a cascaded period-doubling pitchfork bifurcation. For general higher-order autonomous recurrence.

IV. OBSERVATION OF NONLINEARTIES IN DC- AC CONVERTERS

As fig.5 shows, the main basic circuit of an H bridge dc to ac converter fed along with a DC power E includes switches SW1 to SW4 (with the reverse parallel diode) and load.
That circuit is very simply realized through four semiconductor switches, a supply voltage source, an inductor, and a resistor. These turn on-off switches are mentioned as SW1, SW2, SW3, and SW4. This circuit diagram has the following two essential conditions with the controller.

Step A: SW_1 and SW_2: OFFSW_3 and SW_4: ON.

Step B: $SW_1$and SW_2: ON SW_3 and SW_4: OFF.

If the rate of change of current w.r.t. time assume to be "U" then the circuit dynamics is described as

$$U = -\frac{R}{L}i \quad -\frac{E}{L} \qquad \text{State A}$$
$$U = -\frac{R}{L}i \quad -\frac{E}{L} \qquad \text{State B}$$

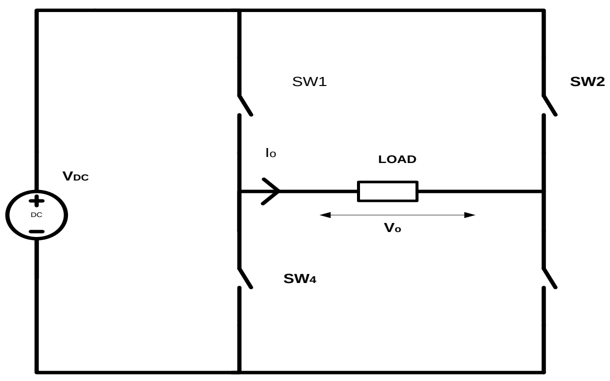

Fig.5: Basic Circuit of H-bridge inverter

Table- I: 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 a variety of dc-ac converter i.e. Inverter load at the output side is to be considered as the bifurcation parameter. Various kinds of simulation results obtained as output load changes as a bifurcation parameter

V. CALCULATION FOR SWITCHING AGLES FOR MULTILEVEL INVERTER SYSTEM:

For phase, delay Values can be obtained as follows

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

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

VI. SELECTION OF PARAMETER VALUESOF PHASE DELAYS FOR THREE LEVELS SINGLE PHASE H-BRIDGE INVERTER:

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

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

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

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

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

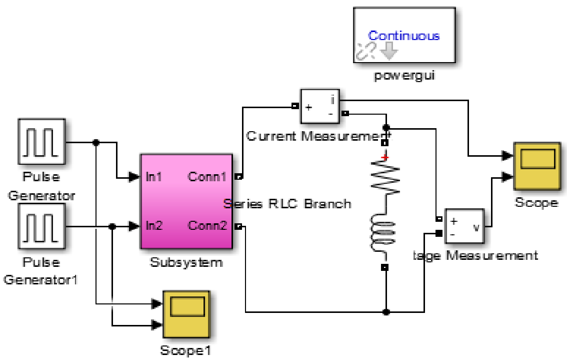

Fig.6: Simulink Model of single-phase inverter

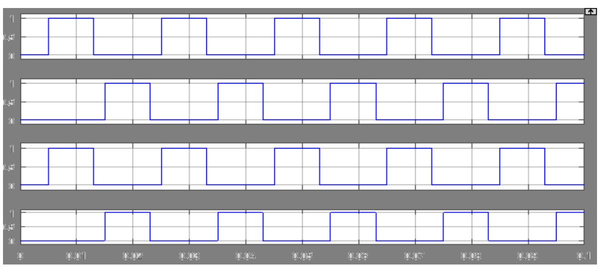

Fig. 7. Switching pulses waveforms from S1 to S4 of H Bridge Inverter

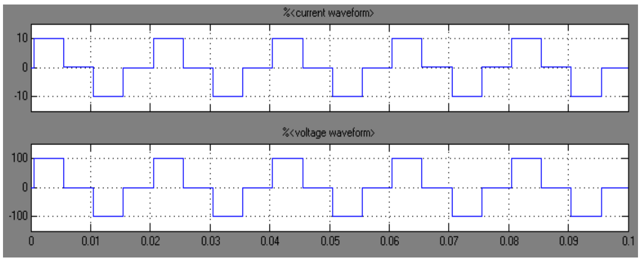

Fig.8. Output Voltage and current waveform of H Bridge Inverter with R load

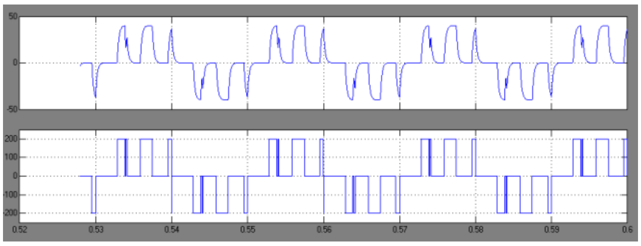

Fig.9. (a) Distorted v Current and Voltage waveform

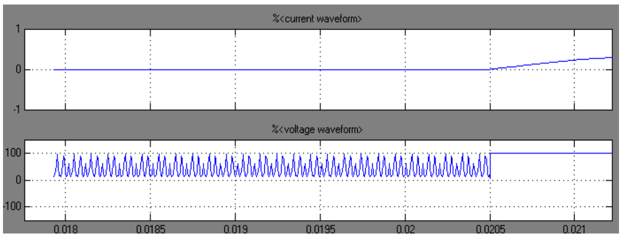

Fig. (b) Enlarge the view of output voltage and current waveform

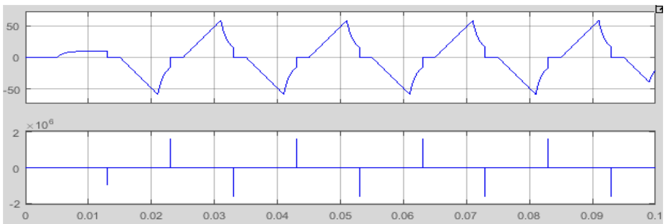

Fig.10.Simulation result of three-level inverter on R=10Ω &L=10mH

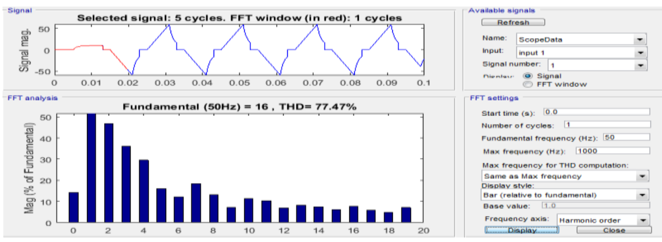

Fig.11.FFT spectrum of three-level inverter for voltage on R=10 Ω & L=10mH

The output waveform of voltage and current for H Bridge single phase Inverter with R-load shown in figure 8 which shows linear behavior (period-1) of system. Figure 10 shows distortion in voltage and current waveform on R-L load and the FFT spectrum shows THD 77.47% which indicates that converter moving towards chaotic mode through bifurcation pathway.

The same operation justified on R=1000Ω and L=100H through inductor current waveform

VII. NONLINEARTIES IN THREE PHASE DC-AC CONVERTERS:

THREE-PHASE INVERTER IS PREFERRED MORE THAN SINGLE-PHASE INVERTERS TO OBTAINED ADJUSTABLE-FREQUENCY AND POWER TO INDUSTRIAL APPLICATIONS,

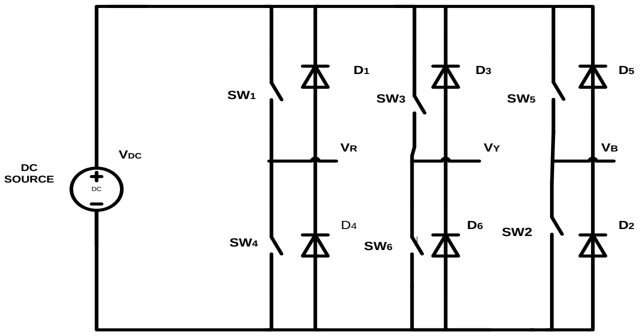

Fig.12. Circuit diagram of the three-phase inverter:

A. Operation Table

Table-II: 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

TABLE III: Showing the Specifications for the different pulse generator

Pulse generator	Delay in degree	Amplitude	Periods (sec)	Pulse width (% of period)	Phase delay (sec)
1	00	3	0.6	50	0
2	600	2	0.6	50	0.1
3	1200	2.5	0.6	50	0.2
4	1800	3	0.6	50	0.3
5	2400	2	0.6	50	0.4
6	3000	2.5	0.6	50	0.5

B. Simulink Model & Parameter Selection: Parameter selection for switching of inverter switch:

To trigger the dc to ac converter switching devices give proper triggering pulses to it using a pulse generator.

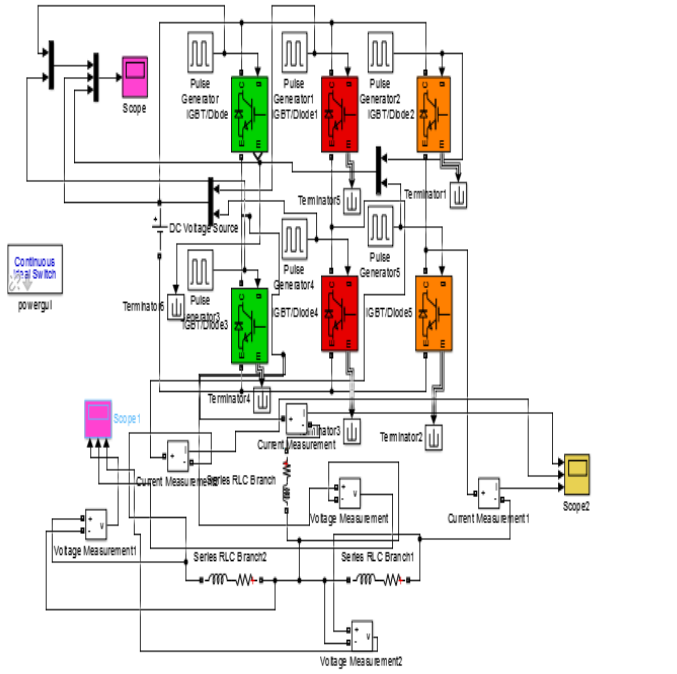

Fig.13.Three-level inverter Simulink model

Desired values can be entered in the block which is obtained by the double-clicking pulse generator. The Pulse Generator generates square wave pulses at a regular interval of time. These square wave pulses are applied to the converter for triggering. The values of parameters of the waveform, Amplitude, Pulse Width, Time-Period and Phase Delay calculate the shape of the output voltage and current waveform. Values for firing delay angle can be obtained as follows

$$0.6\text{ sec}=360^0$$
$$1^0=0.6/360$$
$$60^0=(0.6/360)*60$$

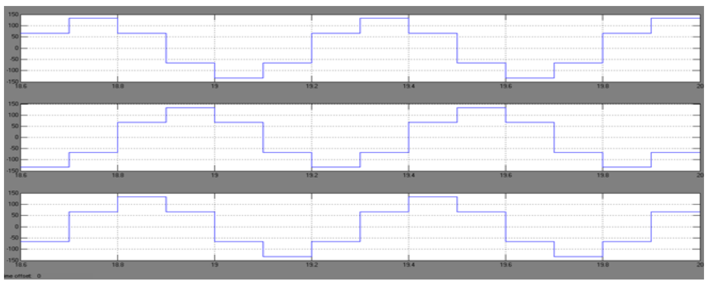

Fig.14. Voltage waveforms of the three-phase inverter with resistive load

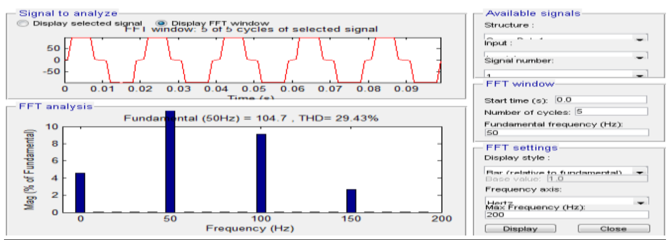

Fig.15. FFT spectrum of three-phase inverter for voltage

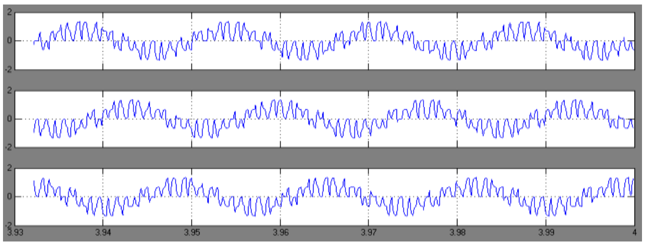

Fig.16. The distorted output waveform of load current after variation in Load

The fast Fourier Transform (FFT) analysis done for voltage to observe and study the reduction in harmonics and this corresponding FFT spectrum is shown in fig.15.and fig.16 that shows a distorted output waveform of load current as load (R_L) varies of the inverter.

VIII. VII. NONLINEARTIES IN CASCADED MULTILEVEL INVERTER SYSTEM

The main differences between a multilevel inverter and a simple inverter are as follows:

- Higher power provided by multilevel inverters.
- The multilevel inverter is operated through several switches instead of one
- Environmental friendly energies like wind and solar energy used as input to inverter and then this dc input convert them to AC.

A multilevel inverter system is a power electronic circuit that is designed for providing required voltage level at the output side by using multiple small level DC voltages as input.

Multilevel VSI (voltage source inverter) system provides an efficient technology and cost-effective in the moderate voltage range and energy management system. All these cascaded multilevel converters have been the widest range of used in oil, chemical and liquefied natural gas (LNG) plants. Power generation and energy transmission, water plants, marine propulsion power-quality devices are the areas were used with great proportion.

Presently, three existing, multilevel voltage-source inverters commercial topologies are in use: flying capacitors (FCs), neutral point clamped (NPC) and cascaded H-bridge (CHB). Multilevel cascaded inverter obtains the higher output voltage, power levels (13.8-kilo Volt, 30 MVA) and the top-level reliability due to its effective modular topology among all these dc to ac inverter topologies,

Cascaded H- bridge multilevel dc to ac converters are based on a series connection of various H-bridge single-phase inverters. This type of design is capable of getting a moderate range of output voltage levels by using only standard low voltage developed technology components. Typically, it is necessary to cascade five inverters in a series manner to obtain the eleven-level of the output voltage.

This dc to ac converters also have a high quality of modularity degree feature due to each inverter can be observed as a module with similar circuit topology, control structure, and modulation. Hence, in the situation when any kind of fault occurs in one of these modules, it is possible to change it easily and fastly. Moreover, with an appropriated control technique, it is possible to bypass the faulty section without breaking the load from module circuit, maintaining an almost regular and continuous overall availability

In a cascade inverter, the number of output phase voltage levels m is defined by m=2s+1, where s denotes the quantity of the separate dc sources. The Phase voltage for an 11 level cascaded H-bridge inverter with five full bridges along with 5 separate dc sources is given by

$$Van=Va_1+Va_2+Va_3+Va_4+Va_5 \quad (3)$$

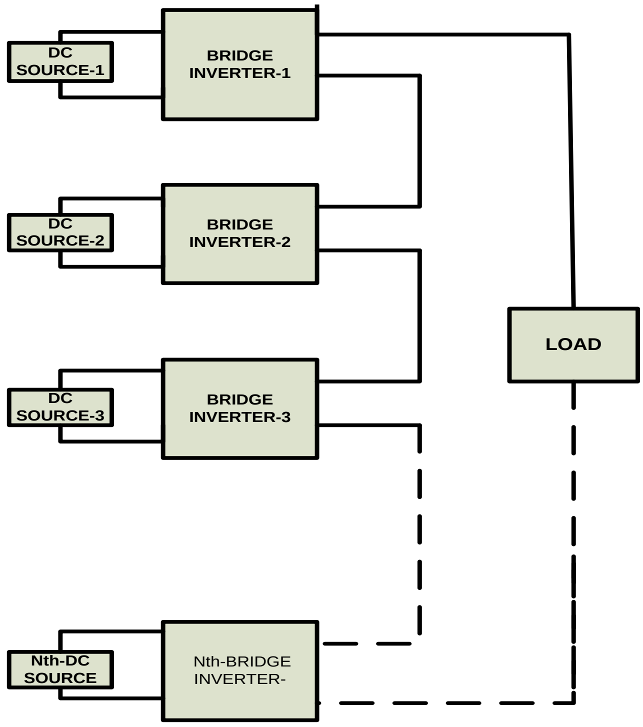

Fig.17. Block diagram of N-level inverter

For a stepped waveform the Fourier Transform for this waveform as follows

$$V(\omega t)=\sum_{n=1,3,5,..}^{\infty} * \frac{4V_{dc}}{\pi n}\left[\mathrm{Cos}(n\theta_1)+\mathrm{Cos}(n\theta_2)+......+\mathrm{Cos}(n\theta s)\right] \quad (4)$$

Where n=1, 3, 5, 7….

From (4) the magnitude of Fourier coefficients when normalized for V_{dc} are as follows:

$$H(n)=\sum_{n=1,3,5,..}^{\infty} * \frac{4}{\pi n}\left[\mathrm{Cos}(n\theta_1)+\mathrm{Cos}(n\theta_2)+......+\mathrm{Cos}(n\theta s)\right] \quad (5)$$

Here n=1, 3, 5, 7, 9….

The conduction angles $\theta 1, \theta 2, \theta 3, \theta 4 \ldots\ldots.\theta s$ can be chosen as that the voltage THD is at a lower level. Generally, these angles are selected such as that predominant low order frequency harmonics, 5th, 7th, 11th, and 13th, harmonics are eliminated.

To reduce the multilevel inverter circuit complexity a subsystem of single-phase H bridge inverter created as shown in fig.18. Through by using this, it is very easy to design high power multi-levels on the single working window.Fig.18 shows the Simulink model of the subsystem for on H-bridge inverter system

Fig.18. Simulink model of the subsystem

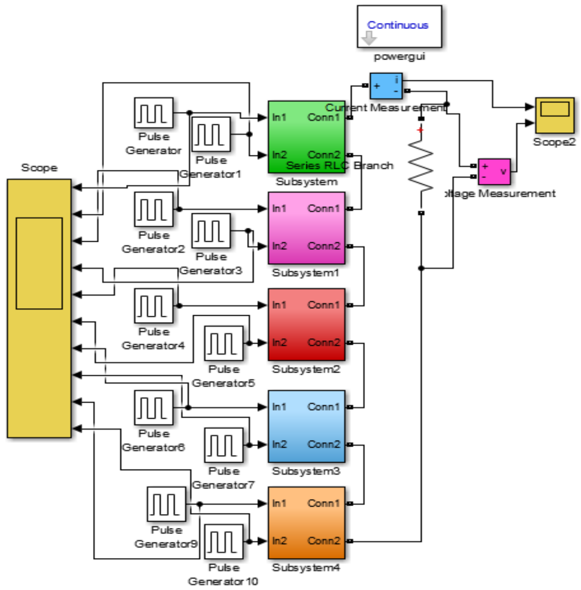

Fig.19.Simulink design model of single-phase eleven levels cascaded H bridge inverter

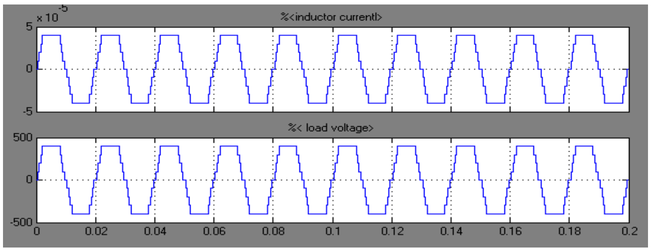

Fig.20. Single-phase eleven level cascaded H bridge inverter Voltage& current waveform

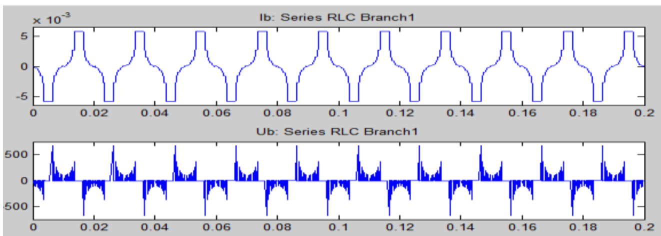

Fig.21. Chaotic Output Current Waveform of eleven level Inverter

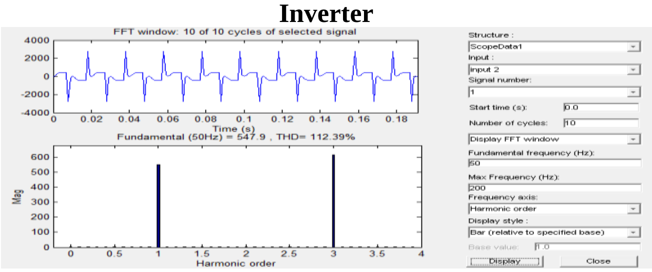

Fig.22.FFT spectrum of eleven level inverter at R=10KΩ, L=650mH for voltage waveform

IX. SELECTION OF PHASE ANGLE DELAYS

A. Eleven-Level Single Phase H-Bridge Inverter:

These firing delay (f.d.) angles given to pulse generators 1, 2, 3, 4, 5, 6 and 7, 8,9,10 blocks for 11 level inverter.

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

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

$\theta 3$ = f.d. ofS1,S3= $\frac{18^0}{360^0}$*0.02 = 0.001

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

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

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

$\theta 7$ = f.d. of S1,S3= $\frac{36^0}{360^0}$*0.02 =0.0020

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

$\theta 9$ = f.d. of S1,S3= $\frac{45^0}{360^0}$*0.02 = 0.0025

$\theta 10$=f.d.of S2,S4 = $\frac{225^0}{360^0}$*0.02 =0.0125

B. Cascaded Three Stepped Three Phase Inverter:

Three individual units of the three-phase inverter are connected to obtain three levels three-phase inverter system. Load at output terminals of the inverter may be connected either in star or delta connected.

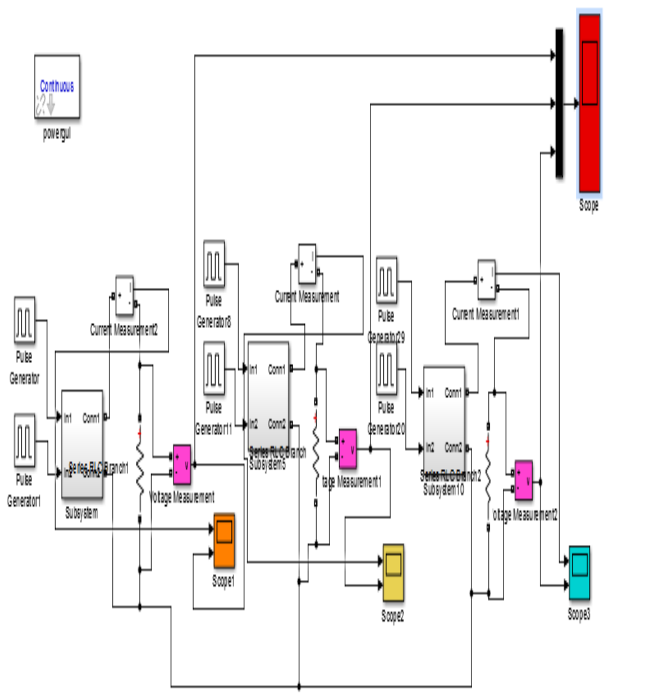

Fig.23. Simulink design model of three-phase three-level H bridge inverter

Case-1-When R=10Ω, V_{in}=100V

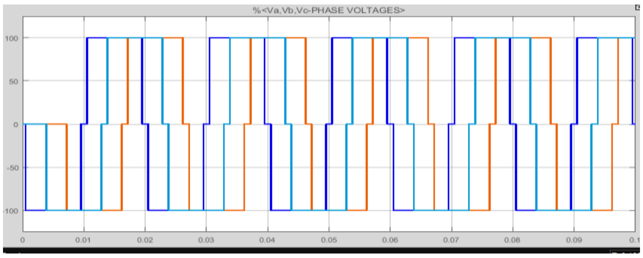

Fig.24.Output phase voltage waveforms of Va, Vb, Vc for three stepped three-phase inverters in period -1

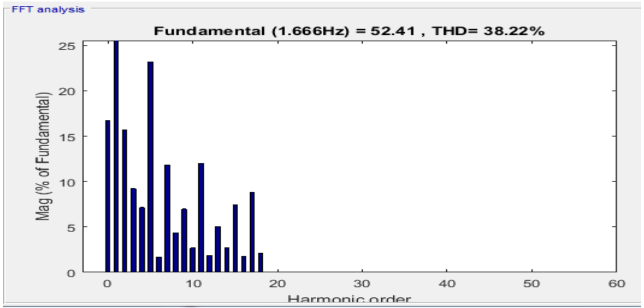

Fig. 25. FFT spectrum for phase voltage Va of three stepped three-phase inverter

Case-2- When V_{in}= 100V, R=10Ω and L=10mH

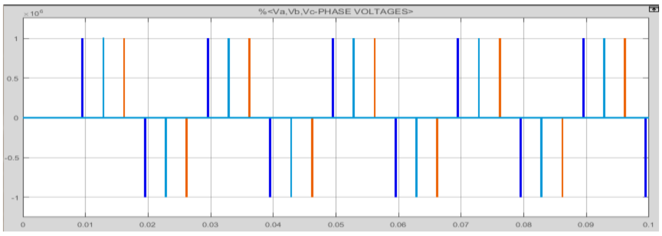

Fig.26.Output phase voltage Va, Vb, Vc of three stepped three-phase inverter

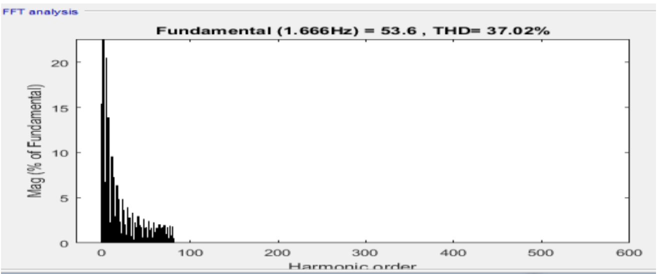

Fig.27.FFT spectrum for phase voltage Va of the three-phase inverter

Case-3- When V_{in} = 100V, R=10ohm and L= 0.1 mH

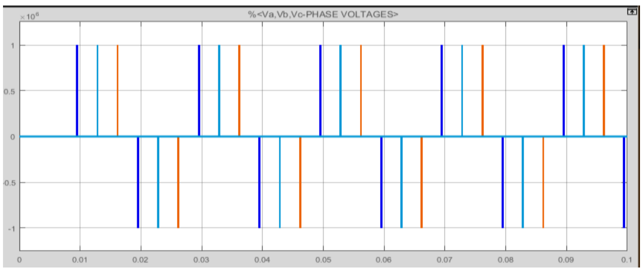

Fig.28.Output phase voltage waveforms of Va, Vb, Vc for three stepped three-phase inverter

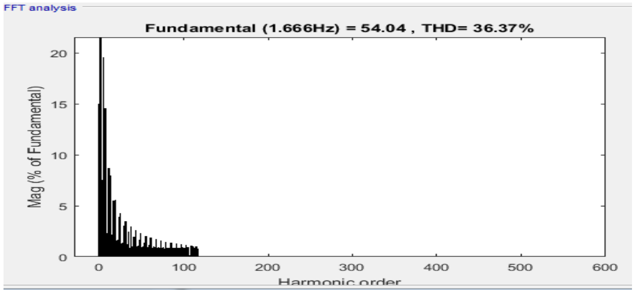

Fig.29.FFT spectrum for phase voltage Va of the three-phase inverter

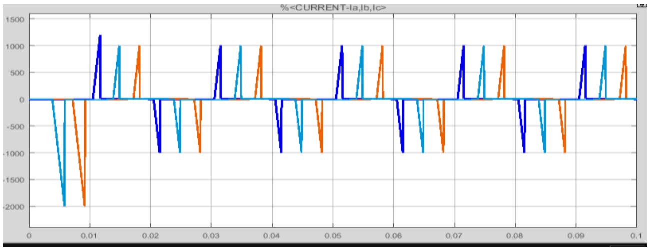

Fig.30.Output phase current waveforms of Ia, Ib, Ic for three stepped three-phase inverter

Table- IV: Showing % THD on Different Values of R And R-L Load of Three Phase Inverter

Particular Load → ↓ Level	% THD			
	Input Voltage	*Resistive Load in Ω R=10 Ω*	*R-L Load, R in Ω and L in mH R=10 Ω and L=0.1mH*	*R-L Load, R in Ω and L in mH R=10 Ω and L=10mH*
Three Level 3-ϕ Inverter	100V	38.22% for Ia 61.64% for Ib 36.97% for Ic 38.22% for Va 61.64% for Vb 36.97% for Vc	36.36% for Ia 63.19% for Ib 35.37% for Ic 36.37% for Va 63.10% for Vb 35.34% for Vc	37.84% for Ia 65.64% for Ib 35.31% for Ic 37.02% for Va 63.22% for Vb 35.41% for Vc

C. Cascaded Three Stepped Three Phase Inverter:

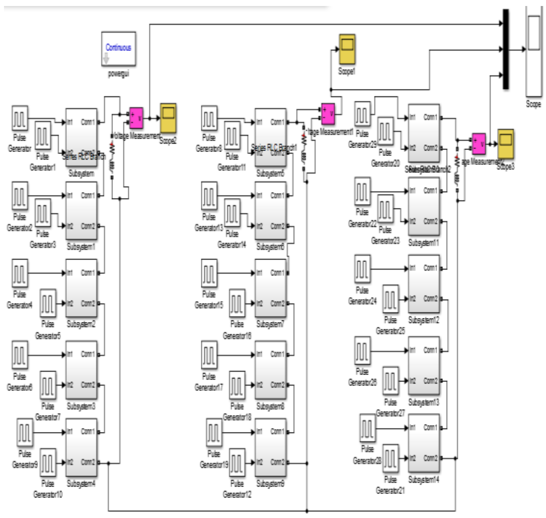

Fig. 31. Complete Simulink model for eleven stepped three-phase inverter

CASE-I When R=10ohm, Vin=100V

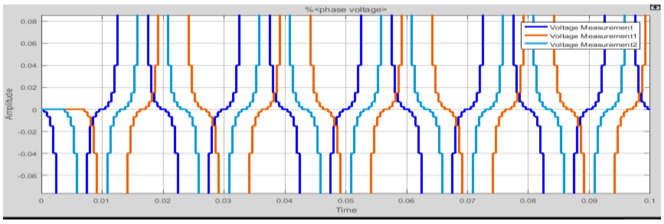

Fig.32. Enlarge the view of output phase voltage waveforms of Va, Vb, Vc for three stepped three-phase inverters in period -1

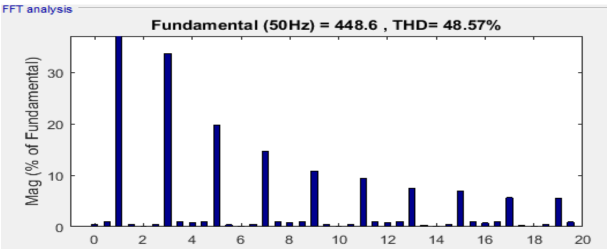

Fig.33.FFT spectrum for phase voltage Va of eleven stepped three-phase inverter

CASE-2- When Vin=100V, R=10Ω, L=10mH

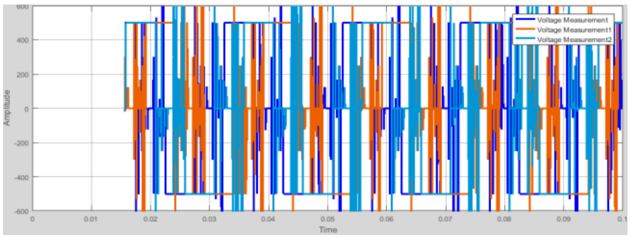

Fig.34.Output phase voltage waveforms of Va, Vb, Vc for three stepped three-phase inverters in Chaotic mode

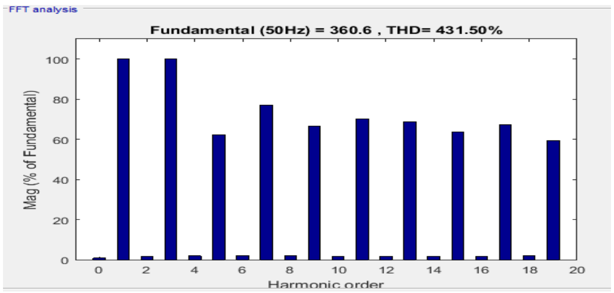

Fig.35.FFT spectrum for phase voltage Va of eleven stepped three-phase inverter

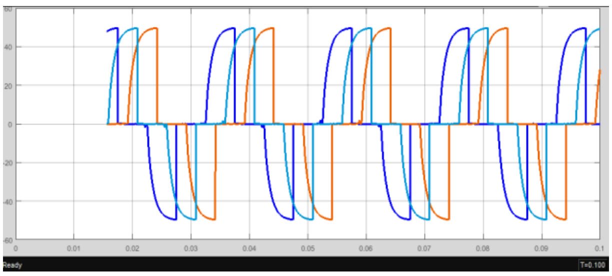

Fig.36.Current waveforms Ia, Ib, Ic for eleven stepped three-phase inverter

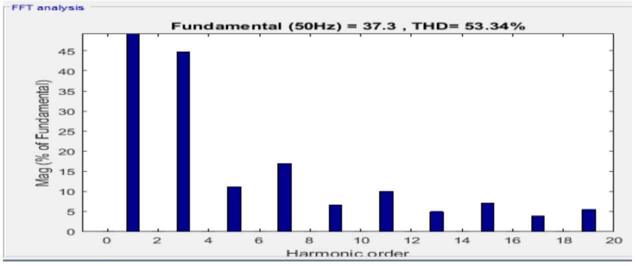

Fig.37 .FFT spectrum for phase current Ib of eleven stepped three phase inverter

CASE-3- When V_{in}=100V, R=10Ω, L=0.1mH

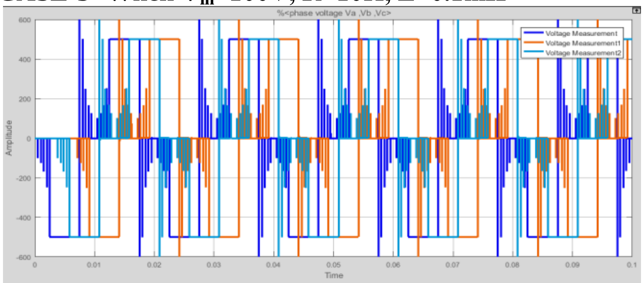

Fig.38. Output phase voltage waveforms of Va, Vb, Vc for three stepped three-phase inverters in unstable mode

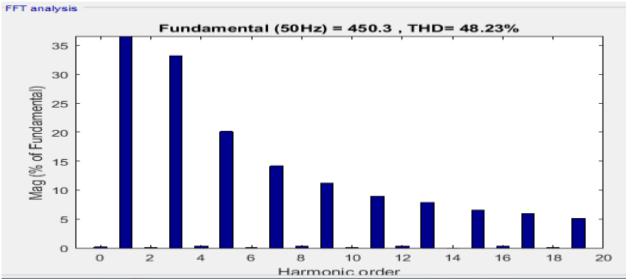

Fig.39.FFT spectrum for phase voltage Va of eleven stepped three-phase inverter

From the above results of fig.19 which shows single-phase, H-bridge cascaded eleven level inverter systems. Fig. 20 showing voltage& current waveform of single-phase eleven levels cascaded H bridge inverter of fig.19. Chaotic Output Current Waveform of eleven level Inverter given in fig.21 and fig.22 showing nonlinear effect by FFT spectrum of eleven level inverter at R=10KΩ, L=650mH for voltage waveform. Simulink design model of three phases three-level H bridge inverter and Complete Simulink model for eleven levels

Three-phase inverter system shown in fig.23 and fig.31 respectively. Three cases are taken into consideration for investigation nonlinear behavior of these converter systems, Voltage and current waveforms are observed in each case at different loads. Fig, 24 to fig.30 showing output voltage and current waveforms and FFT spectrum for eleven levels single phase inverter system to study behavior and understanding how inverter moves towards chaotic mode. Table no. IV showing numerical values of load, percentage THD and supply voltage for that converter. All these observations also taken for a three-phase eleven level inverter system which is shown from fig.32 to fig.39 and table no.V indicates numerical values of that eleven level inverter system for supporting and to justify about complex behavior due to nonlinear effect of circuit elements.

Table -V: Showing % THD on Different values of R And R-L Load for Three Phase Eleven Level Inverter

Particular	% THD			
Load → ↓ Level	Input Voltage	Resistive Load in Ω R=10 Ω	R-L Load, R in Ω and L in mH R=10 Ω and L=0.1mH	R-L Load, R in Ω and L in mH R=10 Ω and L=10mH
3-Φ, 11-level Inverter	100V	48.57% for Ia 67.67% for Ib 52.07% for Ic 48.57% for Va 67.67%for Vb 52.07%for Vc	48.22% for Ia 92.21% for Ib 55.67% for Ic 48.23% for Va 92.23% for Vb 55.54% for Vc	53.34% for Ia 53.15% for Ib 53.93% for Ic 431.50% for Va 722.65% for Vb 620.49% for Vc

X. RESULT AND DISCUSSION

Simulation results are divided into three parts. In first case simulation results of single phase inverter are shown from fig.7 to fig.11 in which variation in voltage and current waveforms presents inverter behavior moving towards irregular pattern as the load R replaced by different value of R-L load.FFT spectrum clearly shows this in fig.11. In the second case simulation results voltage and current waveform of three phase inverter on R and R-L load illustrated from fig.14 to fig.16.In these waveforms it is clearly observed inverter performance effected by variation in the values of load parameter .FFT spectrum in fig.15 support this result. In third case single and three phase cascaded eleven level inverter voltage and current waveforms are obtained by simulation in Matlab/Simulink. For single phase and three phase cascaded eleven level inverter voltage and current are shown from fig.20 to fig21 and f ig32 to fig 39 respectively. FFT spectrum also taken for voltage and current for both cases to observe irregular pattern of waveform from periodic state as load varies. All simulation results obtained by simulation indicates that proper selection of load parameter values helps to keep the inverter in periodic mode.

XI. CONCLUSION

Single-phase and three-phase multilevel switching dc to ac converter have been simulated in Matlab /Simulink for investigation complex behavior, chaos through bifurcation due to nonlinear effect of power semiconductor elements in the converter system. From the simulation results waveforms and FFT spectrum, it is clear that the inverter system reaches toward the chaotic region from stable state operating conditions when load as the bifurcation parameter varies across output terminals. These all inverters have a very wide range of industrial applications and utilization so it is very essential for the design engineers to have complete detailed information about the circuit nature and behavior of different regions of parameter space. It is often too typical to grasp and understand the basic fundamental concepts of nonlinear dynamics when they were shown in mathematical form.

But the hands-on practice of chaotic nature is user-friendly conditions along with graphical output provided by the simulations of nonlinear power electronics circuits. The analyzing way is also increased by the capability to change and experiment with the circuit parameters. The practical merits of analyzing nonlinearities in power electronics systems is a better understanding of the complex and chaotic behavior of inverters which will very helpful for more reliable, efficient designs implementation and new excellent possibilities of operating regimes that provide help and support for optimizing the better-designed system.

FUTURE SCOPE

As new electrical and electronics applications continue to emerge in power electronics, new nonlinear problems are posed. The development of an analytical method to characterize such problems will continue to advance. At the current rate of development, we expect and hope to see meaningful applications of the nonlinear study of power converters. This should be the ultimate aim of all the past efforts spent in characterizing the nonlinear dynamics of power electronics circuits and systems. Although the work has been done for the DC-AC converter, the work may be extended to rectifiers and choppers (DC-DC converters). It is accepted that such converters may also undergo a chaotic operation, which can be studied in future work.

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: unboundedness, 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. J. Deane, D. D. Hamill. Instability, subharmonics, and chaos in power electronics circuits. IEEE Transactions on Power Electronics, Vol. 5, No. 3, 1990, 260-268
7. C. K. Tse. Complex Behavior of Switching Power Converters (CRC Press, Boca Roton 2003)
8. X. K. Ma, M. Li, D. Dai. Reviews of research on the complex behavior of power electronic circuits and systems. Transactions of China Electrotechnical Society, Vol. 21, No. 12, 2006, 1-11
9. B. Robert, C. Robert. Border collision bifurcations in a one-dimensional piecewise smooth map for a PWM current-programmed H-bridge inverter. International Journal of Control, Vol. 27, No.75, 2002, 1356-1367

10. X. M. Wang, B. Zhang. Mechanism of border-collision bifurcations and chaos in H-bridge direct current chopper. Proceeding of the CSEE, Vol. 29, No. 9, 2009, 22-26
11. H. H. C. Iu, B. Robert. Control of chaos in a PWM current-mode H-bridge inverter using time-delayed feedback. IEEE Transactions on Circuits Systems, Vol. 50, No. 8, 2003, 1125-1129
12. X. M. Wang, B. Zhang. Study of bifurcation and chaos in single—Phase SPWM inverter. Transactions of China Electrotechnical Society, Vol. 24, No. 1, 2009, 101-107
13. Rajesh Kr Ahuja, Lalit Aggarwal, Pankaj Kumar "Simulation of Single-Phase Multilevel Inverters with Simple Control Strategy Using MATLAB"IJAREEIE, Vol. 2, Issue 10, October 2013
14. P. C. Loh, D. Holmes, Y. Fukuta, and T. Lipo, "Reduced common-mode modulation strategies for cascaded multilevel inverters," IEEE Trans. Ind. Appl., vol. 39, no. 5, pp. 1386–1395, Sep./Oct. 2003.
15. Y. Sozer and D. Torrey, "Modeling and control of utility-interactive inverters," IEEE Trans. Power Electron., vol. 24, no. 11, pp. 2475–2483, Nov. 2009.
16. M. Hagiwara and H. Akagi, "Control and experiment of pulse-width modulated modular multilevel converters, "IEEE Trans. Power Electron., vol. 24, no. 7, pp. 1737–1746, Jul. 2009.
17. Naihong Hu, Yufei Zhou_, Junning Chen "Study on Chaotic Control of SPWM Inverter and Its Optimization, " Journal of Information & Computational Science 9: 2 (2012) 497-504.
18. 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)

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