Journal of Critical Reviews

ISSN- 2394-5125 Vol 7, Issue 2, 2020

Review Article

TRANSFER FUNCTION CENTERED PID TUNING IN CASCADED MULTILEVEL INVERTERS BASED ON PSO TECHNIQUE

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Received: 05.11.2019 *Revised: 12.12.2019* *Accepted: 30.01.2020*

ABSTRACT
Harmonic elimination in multilevel inverters nowadays a worthy talk in industries because of its high power and high voltage facilities. THD of the multilevel inverter should be reduced and a fundamental voltage component has been maintained. In this paper a new massive technique presented in the minimization of harmonics by calculating the transfer function of the eleven level cascaded multilevel inverter. The stability of the system also measured using Root locus, Bode analysis and assured the stability. Particle swam optimization (PSO) technique used to tune the parameters such as KP,KI,KD in closed loop control system. The optimization technique presented for a same DC sources. The software used in the paper is MATLAB Tool package. The transfer function and PID parameters were calculated by MATLAB software.

Keywords: Cascaded Multilevel Inverter (CMLI), Transfer Function, THD, Equal Dc Sources, Closed Loop Controller, PSO, PID Parameters, Stability Analysis.

DOI: http://dx.doi.org/10.31838/jcr.07.02.27

INTRODUCTION

Semiconductor industry and technology produced a vital converter called Inverters with high power and high voltage inverters. Multilevel inverter is the combination of different inverters and the combination of the inverters where in terms of phase, topology and levels. It pays an important role because of it high performances and low electromagnetic interference.

Multilevel inverter are basically single and three phase. The output of the multilevel inverter is a stepped waveform and it gained it attractively because the quality of output voltage and current waveform are near to the sinusoidal voltage waveform. Basically there are three types of multilevel inverter such as cascaded multilevel inverter, Diode clumped inverter, and capacitor clamped multilevel inverters. Cascaded multilevel inverter consist of series of H-bridges connected.

In diode and capacitor clamped multilevel inverters flying capacitors and diodes are needed in abundance. The inverter produce AC output voltage but a Multilevel inverter produce series of output voltage ie, different level of output voltage. The total harmonic distortion of the multilevel inverter will be less as the output voltage has the capability to produce different levels of outputs. The THD is still reduced by different techniques. The Multilevel inverter consists of different switches and the switching angles will be different and can be found by different methods. The switching angles can be found to reduce the THD of the inverter. Basically used methods are interactive and optimization methods.

The regular method such as Newton method is normally followed and this is based on the initial guess [1][29][35].Modified particle swam optimization technique is based on the swam optimization method. And closed loop optimization algorithm used for the load voltage stabilization and lower the THD [1][4][11].The closed and open loop techniques followed for the for the reduction of THD. Fly optimization technique is based on the olfactory and visual nature of fruit fly in open loop system Fly optimization is used to find the switching and open loop [20] for the multilevel inverter.

In closed loop algorithm for turning of closed loop parameters fruit fly techniques used. Self-tuning controller used normally for the PID parameters calculation and is based on the Modified fly optimization based food finding behavior of Fruit flies [10].Genetic algorithm is used to find the switching angles for the reduction of harmonics. Genetic algorithm is an optimization technique, solves the problem by either maximizing or minimizing the objective function by imitating or mimicking biological process.

To use a genetic algorithm, we must represent a solution to our problem as a genome or chromosome.

The genetic algorithm then creates a population of solutions and applies genetic operators such as selection mutation and crossover to evolve the solutions in order to find the best ones. Once the following three steps have been defined, the generic genetic algorithm should work fairly well. (1) Definition of the objective function, (2) definition and implementation of the genetic representation, and (3) definition and implementation of the genetic operators. Beyond that we can try many different variations to improve performance, find multiple optima or parallelize the algorithms [7][13][14][24].Bee algorithm used to find the switching angle and is based on food foraging behavior of honey bees.[25].By considering the arc length and differential method of switching angles can be calculated by means of homotopy algorithm[27].

CASCADED MULTILEVEL INVERTER

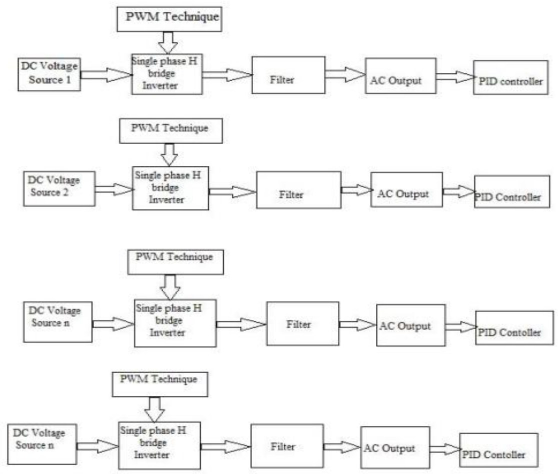

Fig. 1: Block diagram of cascaded Multilevel Inverter

The block diagram representation of eleven level multilevel inverter comprises of a series connected DC source cascaded H bridge inverters, Filters to riddle the output obtained from the H bridges inverters and a PID controller absolutely for closed loop control systems to regulate the output voltage according to the input voltage

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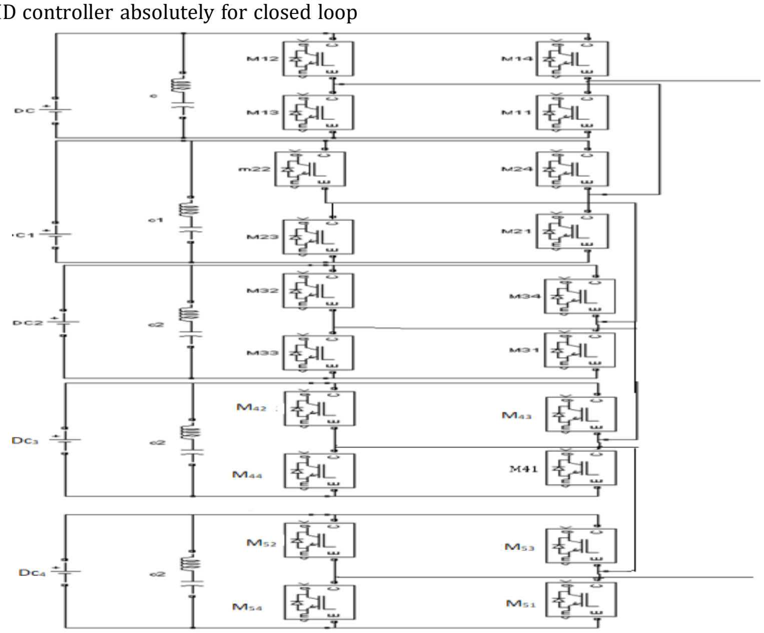

Fig. 2: Circuit Diagram of a Cascaded 11-Level Multilevel Inverter

The prearrangement of cascaded multilevel inverter plumps the type, phase and the configuration of inverters. Out of three type of inverter this paper presents cascaded multilevel inverter. The phase of the inverter such as single phase or three phase inverter and in this paper presenter single phase inverter and different configuration of inverters. In cascaded multilevel inverter the number of switched and power supplies govern the level of inverters. For 11 level inverter five power supply and five H-bridges castoff. The number of output phase voltage level in cascaded multilevel inverter is 2s+1,where s is the number of DC sources.(2*5+1).The number of voltage sources used for this inverter is (m-1)/2=(11-1)/2=5.m indicates number of levels. The overall switches used for the inverter is 2(m-1)=2(11-1)=20. For five H bridge modules and five individual power supply units each with a power capacity of 24v * 3A = 72 watts. Total rating of the inverter will be 5 * 72 = 360W.The output voltage waveform of the cascaded multilevel comprises of fundamental and have harmonics. Harmonics are frequencies equal to odd integer multiples of the fundamental and harmonics. If the fundamental is 50Hz,then the order harmonics are 150Hz for 3rd,250 for 5th,350 for 7th and so on.(3*50=150,5*50=250 etc).Nth harmonic Vn can be calculated by Vn= $\frac{4*(Vdc*M)}{(n*\Pi)}$ Vdc = Dc input, M=Modulation index Vn=Peak fundamental. If all stages in multilevel inverter operates with equal Vdc, Modulation index and simultaneous switching then the amplitude, frequency and phase are identical. The stages are turned on one by one output voltage levels are incremented uniformly. Switching should be given in each stage with different switching angle ($\alpha_1 < \alpha_2 < \alpha_3 < \alpha_4 < \alpha_5$).

Switches	Output voltages					
	V_0	V_1	V_1+V_2	V_1+V_2+V_3	V_1+V_2+V_3+V_4	V_1+V_2+V_3+V_4+V_5
M_{11}	0	1	1	1	1	1
M_{12}	0	1	1	1	1	1
M_{13}	0	0	0	0	0	0
M_{14}	0	0	0	0	0	0
M_{21}	0	0	1	1	1	1
M_{22}	0	1	1	1	1	1
M_{23}	0	0	0	0	0	0
M_{24}	0	0	0	0	0	0
M_{31}	0	0	0	1	1	1
M_{32}	0	1	1	1	1	1
M_{33}	0	0	0	0	0	0
M_{34}	0	0	0	0	0	0
M_{41}	0	0	0	0	1	1
M_{42}	0	1	1	1	1	1
M_{43}	0	0	0	0	0	0
M_{44}	0	0	0	0	0	0
M_{51}	0	0	0	0	0	1
M_{52}	0	1	1	1	1	1
M_{53}	0	0	0	0	0	0
M_{54}	0	0	0	0	0	0

Fig. 3: Switching sequence of cascaded Multilevel Inverter

For the output voltage of level 0 all the switches in the H-bridges are turned off so the output voltage is zero. For the first level output SwitchT1 and T1' of first Hbridge and all the upper positive switches of other H bridges are turned on. For the second level output first and second H-bridge alternate switches and the upper positive switch of other H-bridges should be turned on and respectively for other output voltage levels.

PULSE GENERATION FOR CASCADED MULTILEVEL INVERTER

The switches of the cascaded multilevel can be triggered using different pulse generation technique. The main PWM techniques such as single PWM, step Modulated PWM, space vector PWM, Sinusoidal PWM, Multicarrier sinusoidal PWM, Selective harmonic elimination PWM technique, Equal area concept, selective point pivoting with sinusoidal reference PWM. In this paper a sinusoidal pivoting technique is used for the pulse generation.

Selective Point Pivoting Sinusoidal Reference Technique

Spot a scratch on a sine wave with alike heights starting from 0.15 level. The output voltage of 11-level inverter the positive half cycle has five values. If each source voltage is say 35 V then the overall voltage is 175V. With a 175 v dc source the peak value of the output AC voltage is given byV (peak of ac fundamental) = ((4 *Vdc)/pi) * MI where MI is the modulation index. With MI = 1, the V (peak of ac fundamental) = 700/pi = 223 v.In this sine wave the values of 35v,70,105v,140v and 175 volts occur at the angles α1, α2, α3, α4, and α5 respectively. By the fundamental relationship V(t) = Vmax (SIN α),α=Sin inv(V(t)/Vmax).If the modulation index is less than 1 say 0.5 then, V (peak of ac fundamental) = ((4 *175)/pi)* 0.5 = 111.5v.For a 111.5 V peak value the calculations are repeated to find the values of α1, α2 and α3, α4, α5.Whenever the modulation index is changed, Calculate the peak value for that MI, Check how many levels will be necessary.

Serial No	Step No.	V level	Angle in Degrees. ϴ=Sin inv(Vlevel)	occurrence Micro Sec. ((10e^-3)/90)*angle	Levels in Action
1	0	0	0	0	0
2	1	0.15	8.626	480	1
3	2	0.3	17.457	970	1,2
4	3	0.45	26.74	1486	1,2,3
5	4	0.6	36.86	2048	1,2,3,4
6	5	0.75	48.59	2700	1,2,3,4,5
7	5	1	90	5000	1,2,3,4,5

Serial No	Step No.	V level	Angle in Degrees. ϴ=Sin inv(Vlevel)	occurrence Micro Sec. ((10e^-3)/90)*angle	Levels in Action
1	0	0	0	0	0
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6	5	0.75	48.59	2700	1,2,3,4,5
7	5	1	90	5000	1,2,3,4,5

Fig. 4: Levels-Quadrant I and II Raising and Falling Levels

CLOSED LOOP CONTROL SCHEME

Closed loop control scheme that regulated the output voltage. In a closed loop control system there will be the original output and the regulated output the regulated output can be obtained by the comparison of the error signal and the original input. A comparator will be present in the closed loop system it compares the original input with the desired input and produce as error .

signal. According to the error signal generated the output will be automatically adjusts based on the controller parameters.PID controller manipulates the Modulation Index automatically. Soft computing based optimization turning methods used for tuning the controller parameters. This paper used Particle swam optimization algorithm based on transfer function analysis for the tuning of kp, ki and kd values

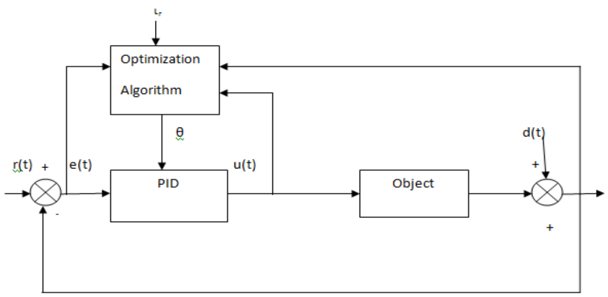

Fig. 5: Closed Loop Controller

Transfer Function Analysis

Transfer function is a compact model of input and output of the system. It gives the relationship between input and output connecting transfer functions. For a linear input output systems

$$\frac{d^n y}{dt^n} + \frac{a_1 d^{n-1} y}{dt^{n-1}} + \ldots\ldots a_n y = \frac{b_0 d^m u}{dt^m} + \frac{b_1 d^{m-1} u}{dt^{m-1}} + \ldots\ldots\ldots b_m u$$

Where u is the input and y as output. The differential equations are the characteristic polynomial of the system defined as numerator polynomial and denominator polynomial. Normally output of a complex system is written in transfer function as,

$$y(t) = \frac{\text{output}}{\text{Input}}$$

$$y(t) = \frac{b(s)}{a(s)} = G(s) \text{ Transfer Function}$$

The system transfer function for the proposed closed loop eleven level inverter can be obtained from the simulation diagram and can be found out using system transfer function command. System transfer function of eleven-level inverter is

$$\frac{2.81S^2 + 5.304e04S + 6.57\,e^{07}}{2^3 + 1309S^2 + 1.812\,e^{05}S + 6.57\,e^{07}}$$

```
Command Window
  Parameterization:
    Number of poles: 3   Number of zeros: 2
    Number of free coefficients: 6
    Use "tfdata", "getpvec", "getcov" for parameters and their uncertainties.

  Status:
  Estimated using TFEST on time domain data "mysys".
  Fit to estimation data: 100% (simulation focus)
  FPE: 6.23e-07, MSE: 6.224e-07

  sys =

    From input "u1" to output "y1":
      2.81 s^2 + 5.304e04 s + 6.57e07
    -------------------------------------
    s^3 + 1309 s^2 + 1.812e05 s + 6.57e07

  Continuous-time identified transfer function.

  Parameterization:
    Number of poles: 3   Number of zeros: 2
    Number of free coefficients: 6
    Use "tfdata", "getpvec", "getcov" for parameters and their uncertainties.
```

Fig. 6: Poles and Zeros for the Transfer Function Analysis

Stablity Analysis

System Response of Eleven Level Inverter

Basically system response of the closed loop system is classified into two types

1) Time Response Analysis
2) Frequency Response Analysis

We can plot step and impulse response of the system by means of step (sys) and impulse (sys). The linear response of the system can be identified using lsim. lsim(sys, u, t)

The initial response of the system can be classified using initial command.

Frequency Response Analysis

To analyze the stability and performance properties of control system bode, Nichols and Nyquist are the basic and standard commands.

Pole/Zero map and Root Locus

Normally gain value is K = 0.7 to plot the closed loop poles and zeros. K = 0.7,T = feedback (sys x K, 1),Pzmap(T),Pole-Zero Plot with gain 0.7.The closed loop poles lies in the left half of the Z plane which indicates system is stable.

Root Locus

Root locus intersects the y-axis and reveals the close loop poles become unstable.

Steady State Gain of the System

Steady state is defined as the ratio of output and input of the system before run time. That means in the initial condition

$$\frac{y_0}{u_0} = \frac{bn}{a_n} \equiv G(0)$$

Poles and Zeros

The roots of the polynomial b(s) when equating to zero called zero's of the system and when the roots of the polynomial a(s) when equating to zero we can obtain poles of the system.

PID Tune

Tuning rules are the set of formulas where controller parameter has been determined. ZN - The tuning rules are based on the formula tuning. In the proposed work of tuning PI controller using Z-N method, the obtained parameter values are kp=0.32,ki=2.5.PID tune is the software based tuning. Kp=4.9,ki=493.5,kd=0.01243 and THD=10.42%.Turning using optimization technique is based on evolutionary computation algorithm.

PSO OPTIMIZATION ALGORITHM

The closed loop control parameters can be evaluated from optimization algorithm. This paper chooses a particle swam optimization algorithm's for closed loop analysis. Particle swam optimization is purely based on swam flocking technique. Basically the size, number of steps, dimensions, parameters, movement of inertia for velocity and position got initialized. The next step is used to find the fitness and to initialize the PID parameters, initialize the simulation of transfer function and to compute error and overshoot. Then update the values of p best and gbest. The plant consists of step and the controller the output of the controller is applied to the actuator. The actuator has a plant. The plant has the transfer function of the cascaded eleven level inverter and the output is spread to the scope.

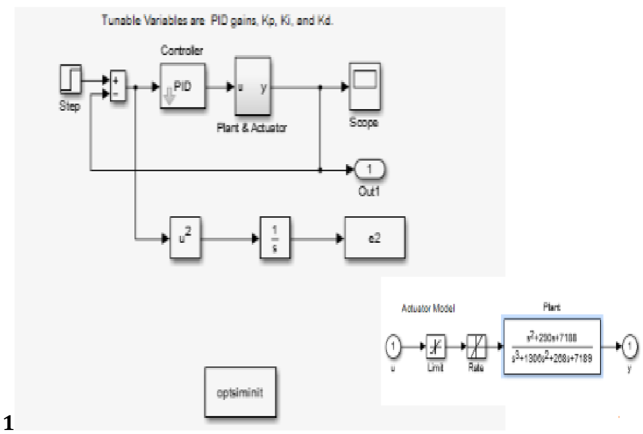

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Fig. 7: PSO Technique for Closed Loop Parameter Finding

SIMULATION DIAGRAM

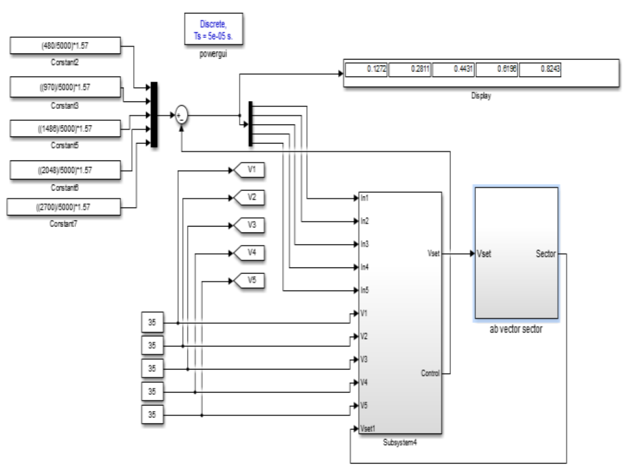


Fig. 8: Simulation Diagram Using Sinusoidal Pivoted Technique and PSO Algorithm for Controller Parameters

The simulation diagram of cascaded eleven level inverter has 20 switches and the switches are fed by the pulse generation unit. The pulse of the switches can be find out using sinusoidal reference technique. The pulse values are feed into the inverter and the controller parameters are evaluated from the

SIMULATION OUTPUT

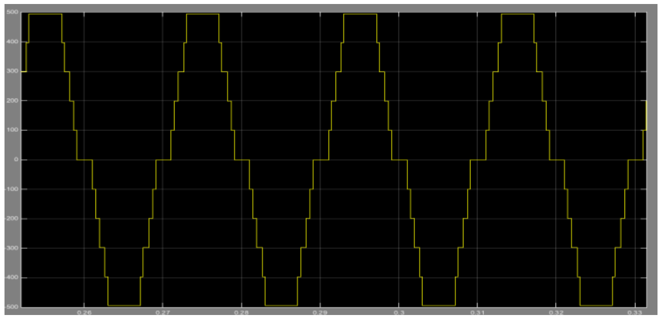


Fig. 9: Simulation Output for 11 Level Inverter without Filter

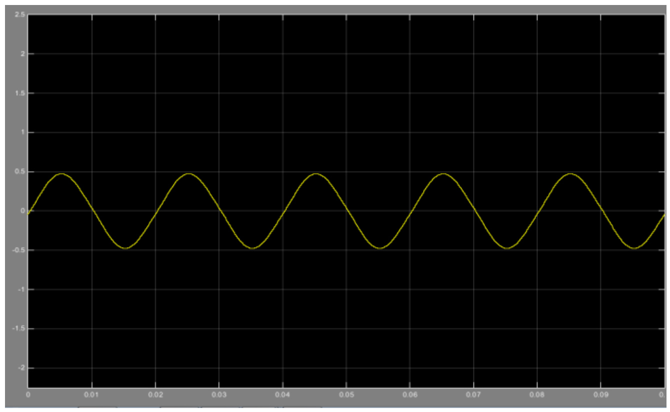
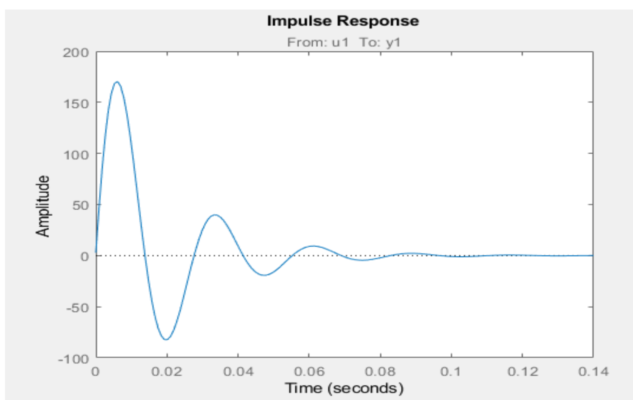
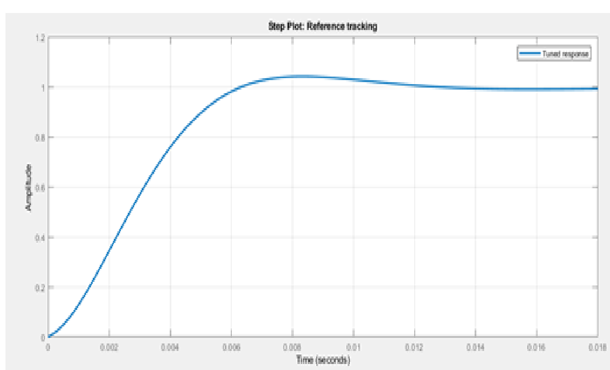


Fig. 10: Simulation Result for 11-Level Inverter with Filter





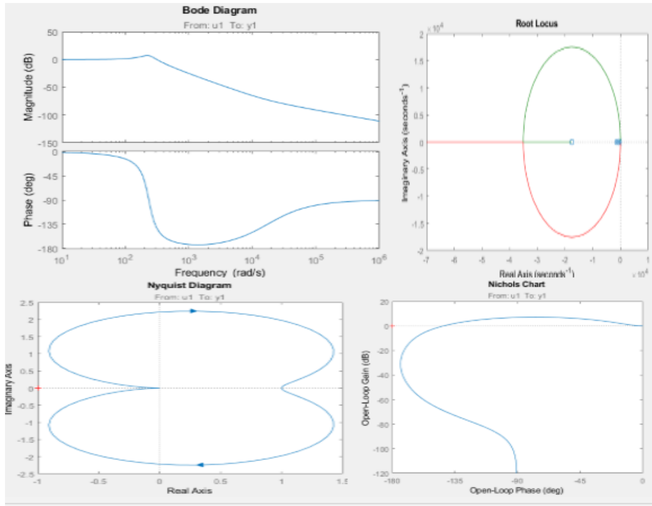


Fig. 11: Stability Analysis for the 11 Level Inverter

The stability analysis of the inverter can be analyzed using the closed loop control stability analysis criteria such as Root locus, Bode plot, Nyquist diagram and Nichilous chart. The Fig11 states the stability analysis of the 11-level inverter by various techniques. The result obtained during the analysis clearly states the system is stable.

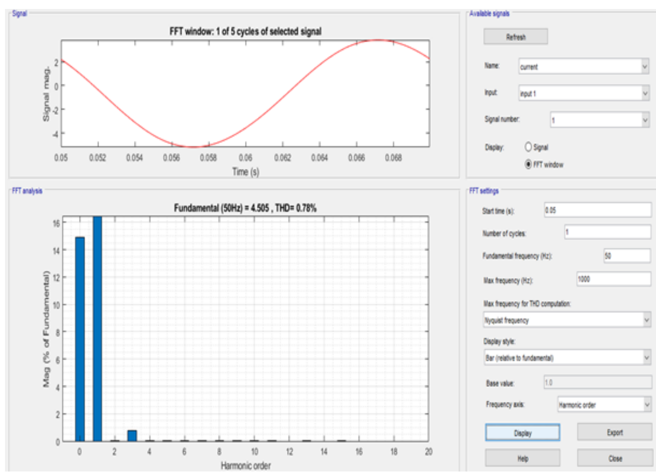


Fig. 12: THD Using Particle Swam Optimization

CONCLUSION

This paper shows the cascaded eleven level inverter and the switching angles and obtained by a PWM techniques called sinusoidal pivoted reference and a closed loop system is constructed and the closed loop parameters such Kp, Ki, Kd values found out using various methods such as Ziegler Nicolas method, PID tune command using MATLAB, and Particle swam optimization method. The result obtained using PSO springs the auspicious output which has the proficiency to diminish the total harmonic distortion of a closed loop inverter to 0.75%.The stability of the cascaded eleven level inverter is establish from the transfer function and evidences the system is stable.

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